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INCENTIVES FOR RECYCLING AND REUSE OF PLASTICS

Jack Milgrom

Arthur D. Little, Incorporated
Cambridge, Massachusetts

1972

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U.S. ENVIRONMENTAL PROTECTION AGENCY

1972

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FOREWORD

ALTHOUGH PLASTICS are only one of the many components found in the solid waste stream, they present unique problems in solid waste management as they are relatively new materials, and their disposal characteristics are not fully known. Moreover, much of the available information about the disposal of plastics is based on very limited data, which are often not viewed in their proper perspective.

Because they are derived from limited petroleum resources, and because the market for these relatively new materials is growing rapidly, effective management of waste plastics is becoming more essential.

This study was initiated to add to our basic information about plastics in the solid waste stream and in response to mandate of the Resource Recovery Act of 1970 to investigate incentives to accelerate the reclamation or recycling of materials from solid wastes. Although other studies have developed information in this area, this is the first to explore the use of incentives in encouraging the recycling of materials. It should be viewed as a pioneering effort that can serve as a base for developing a resource recovery policy. David S. Thelen served as the project officer during the course of the study.

--SAMUEL HALE, JR.
Deputy Assistant Administrator
for Solid Waste Management Programs

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Jack Milgrom, Senior Staff, Polymer Chemist, was the Case or Project Leader and was assisted by the following specialists: George Pickering, Plastics Fabrication; Charles Jenest, Marketing Analysis; Aaron Brody, Packaging Technology; Walter Niessen, Solid Waste Disposal; Irving Plotkin, Economist; Martin Stankard and Christoph Maier-Rothe, Operations Research; and Robert Eller, Plastics Specialist.

Many individuals and organizations provided information, advice, and commentary to this research team. We should like to express our thanks and appreciation to all those who assisted us.

In particular we wish to thank Mr. David Thelen of the Division of Technical Operations, Office of Solid Waste Management Programs, who was project monitor for this work. His assistance, guidance, and patience were appreciated in carrying out this rather difficult study which is one of the first incentive or policy studies designed to promote recycling of one of the important materials in the solid waste stream.

This study would not have been carried out without the generous cooperation of many companies and associations. Some of the participating organizations are listed below.

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Keep America Beautiful	New York, New York
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Others

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GLOSSARY OF SPECIAL TERMS

Composite - The end item contains both plastic and nonplastic materials firmly bonded together.

Compound - Polymer mixed with any additive or additives, whether they are antitoxidants, colorants, plasticizers, or fillers.

Compounding -- The process of mixing polymer with additives or colorants.

Converter - One who uses a fabricated plastic product as raw material and further modifies it by processes such as printing, cutting, or sealing.

Fabricator - One who uses a resin as raw material to make a plastic or a plastic-containing end item, which may be plastic film or bottles, or plastic-coated paperboard.

Film - An optional term for sheeting having a nominal thickness not greater than 0.0.0 inches.

Monoplastic - The plastic end item contains one plastic compound.

Multiplastic - The plastic end item contains more than one plastic compound, as in a laminate.

Nuisance Plastic (NP) - That portion of total plastics production that has no value and is usually found in the disposal area.

Polymer - A macromolecule whose structure can be represented by a repeated unit called the monomer. Polymers can be fibers, elastomers, or plastics, depending upon the chemical structure of the molecule. This study is concerned only with plastics; therefore, in this study the term polymer describes the material manufactured by the resin producer when in contains no additives.

Processing - The process of transforming polymer or compound to a useful plastic item.

Recycling-primary - Scrap plastic is reformed (usually remelted) into its original form.

Recycling-secondary - SP is reprocessed into another plastic form.

Recycling-tertiary - SP is converted into energy or another nonplastic product such as oil, etc.

GLOSSARY OF SPECIAL TERMS (Cont'd)

Reprocessing - The process of converting scrap plastic (SP) to a useful product.

Resin - A general term signifying either polymer or compound.

Reuse - Spent product is used over again in its original form. It is not remelted.

Scrap Plastic (SP) - This plastic has value and is generated by the resin producer, compounder, fabricator, or converter in his operations. It can also be recovered from the solid waste stream. Usually this material requires reprocessing; i.e., it must be subjected to an additional heat history.

Secondary Resin - Resin produced by reprocessing scrap plastic. This material has been subjected to more than the minimum number of heat histories.

Virgin Off-Grade Resin - Same as Virgin Prime Resin, but the resin as prepared did not meet the original customer's specifications. Generally this product has a wide specification range and is used for less critical plastic end items. Resin produced in a continuous operation as the manufacturer changes his line from one grade to another, the so-called "transition" material, and that produced in experimental runs, are other examples of off-grade resin.

Virgin Prime Resin - A resin that during production undergoes a minimum number of heat histories and meets the required specifications. If compounding is needed, it may be carried out as a single or multistep process; the product is still considered virgin.

INTRODUCTION

Plastics are one of the major materials in use today, and in the 1980's more products will probably be made from plastics than from any other material including steel. The production of plastics in 1970 was 20 billion pounds, and this is expected to rise to more than 50 billion pounds per year by 1980. This rapid growth is due to the many advantages offered by plastics, namely lightweight and good strength, freedom in design, ease of fabrication, and low cost.

In spite of the extensive use of plastics, plastics account for less than 2 percent of the solid waste. The disposal of plastics is very much in the public's eye today, because plastics are a relatively new material, and their disposal characteristics are not well known. Today essentially none is being recycled from the consumer. On the other hand, materials such as metals, glass, and paper are being recycled, and this recycling will, no doubt, increase during the coming decade. Therefore, the concentration of plastics in solid wastes could become more significant.

This study is the first of a series of incentive studies that include not only the gathering of information related to the problems of recycling materials, but an attempt to find solutions. There were two aspects to this study: (1) to develop a descriptive model of the plastics cycle; (2) to develop complete strategies for promoting the recycling and reuse of plastics. During this study we interviewed all segments of the plastics cycle from resin producer to supermarket personnel. Considering the technical and economic impediments uncovered during the study, we then examined the realistic possibilities of promoting recycling. Although this study has been restricted to plastics, we hope that we have helped provide the methodology for investigating the feasibility of recycling other materials.

For the sake of our analysis, we carefully defined terms commonly used by industry and developed new ones, as required. (A glossary of terms appears in this Report.) The words reuse and recycle, for example, are often used interchangeably. Here, however, we take reuse to mean that the package, for example, is used over again in its original form. The returnable bottle is an excellent example. Recycling, on the other hand, implies that the spent packaging material or any other spent plastic product is reprocessed, which in the case of plastics can mean that it is remelted and reformed. In primary recycling, the plastic is reformed into its original form, and in secondary recycling, it is reprocessed into another plastic form. In the case of plastics, tertiary recycling also is possible. Thus, plastics can be pyrolyzed to yield non-plastic materials such as oils, waxes, or greases, or they can be burned as fuel.

We also developed a new term called NP or nuisance plastics, which represents that portion of total plastics production that has no value, and which are usually found in the disposal area. NP can be defined as equal to the cumulative plastics production (PP) minus the cumulative plastics of value (PV). PV consists not only of normal production material but includes scrap plastic (SP) of value that is generated during manufacturing. If this scrap is not used either by the scrap producer or another manufacturer, then it becomes NP. This same classification system can be applied to other materials.

This study is reported in five parts. Part I contains a discussion of the technology of plastics, which provides the basis for understanding the technical problems of recycling. In particular, we describe the various manufacturing processes and indicate the volumes of SP and NP generated and how they are formed.

The economics of the plastics industry needed to develop and assess the strategies for recycling plastics are described in Part II. The economic structure of the plastics industry and the markets for both virgin and secondary materials are discussed. This indicates the nature of the economic impediment to recycling.

In Part III we describe in detail the entire plastics cycle through which all plastics articles pass, as they are manufactured starting from petrochemicals until they become a plastic end product in the hands of the consumer. The relationship between each of the segments of the plastics cycle are described, and the type and volume of NP generated by each is estimated. These data are then used to show the various sources of NP in the disposal area today and as we estimate them to be by 1980.

Part IV provides an analysis of the existing state of the art of methods for isolating plastics from the solid waste stream and of applications for the scrap material. Some of the potential markets for scrap plastic are also noted.

Finally, in Part V the strategies for promoting the recycling and reuse of plastics are developed and described in detail. These strategies and tactics are compared using a set of carefully selected objectives or criteria.

INCENTIVES FOR RECYCLING AND REUSE OF PLASTICS

PART I

THE TECHNOLOGY OF PLASTICS

This is often called the ''Plastics Age.'' But, what are plastics? Everyone is familiar with them. They are used as substitutes for metal, glass, wood, leather, etc., to make a wide range of products including the upholstery you may be sitting on, the numerous items in the automobile you probably drove today, and the packaging used to deliver your food. All of these have one thing in common--they are solid compositions and are moldable.

THE STRUCTURE OF POLYMERS

Plastics are a family of materials. Each member has its special advantages and all are man-made. Chemically, plastics are composed of chain-like molecules of high molecular weight. They are extremely large molecules (macromolecules) called polymers, and are usually synthesized from simpler molecules called monomers. The synthesis process is called polymerization. A different monomer or combination of monomers is used to manufacture each type of plastic material. Polymers, which means ''many parts,'' are useful plastics if they range in molecular weight from a few thousand to several hundred thousand; i.e., if they consist of hundreds and even thousands of repeating monomer units.

Interchain Forces

What gives polymers their physical properties? Ethylene, which is a gaseous molecule, has no physical strength because the molecules can be separated easily from each other by simply overcoming weak intermolecular forces. However, a polymer made from ethylene, polyethylene, has considerable strength because valence bonds have been established between the former ethylene molecules. Furthermore, weak intermolecular forces between sections of the polymer chains are multiplied many times over due to the enormous length of these chains (Figure 1). In the figure valence bonds are indicated by solid lines, while the weak intermolecular or interchain forces are shown as dotted lines. Thus, ethylene molecules in the gaseous state are far apart, and the forces between them are extremely weak; while those in the polymer are close together, and there are strong forces between them. In the latter case, to move one polymer molecule away from its neighbor takes considerable force. In fact, under this stress the polymer chain can rupture rather than move.

Polymer chains in a solid phase are normally highly entangled. When subjected to an extension force, these chains tend to be oriented in the direction of pull. This effect increases the interchain forces of attraction, as discussed in section ''Orientation'' below.

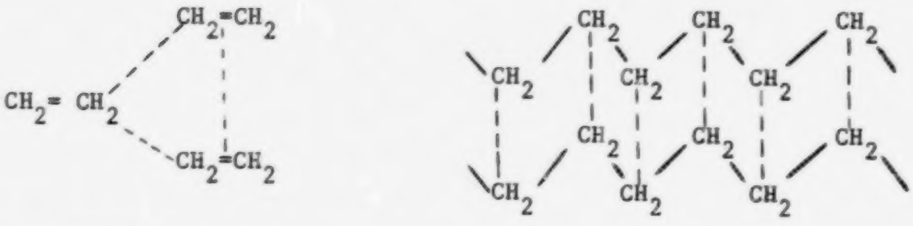
Whether a polymer is suitable as a fiber, rubber, or plastic depends upon the strength of these interchain forces. If they are very great, the polymer can become a good fiber; and if the forces are weak, the polymer is a potential elastomer. But, if the forces are moderate, then plastic behavior is possible. In this case, if the polymer-chains are stretched and partly oriented, they will retain their configuration, even after the extension force is released.

The intensity of these interchain forces is dependent on the chemical structure of the polymer chain, i.e., the type and grouping of the atoms along the chain. Polymers based on the ethylene chain (Figure 2) represent approximately 75 percent of all plastics consumed in 1970 and amount to approximately 14 billion pounds. These plastics are the two polyolefins, polyethylene and polypropylene, together with the styrene polymers and polyvinylchloride (PVC).

Molecular-Weight Distribution

The subscript ''n'' in Figure 2, which denotes the number of repeating monomer units in the polymer represents an average number, because polymers are generally a mixture of molecules having different sizes or molecular weights. Thus, the properties of polyethylene or a similar plastic depends on how many of each size and shape molecule are present in the given mixture.

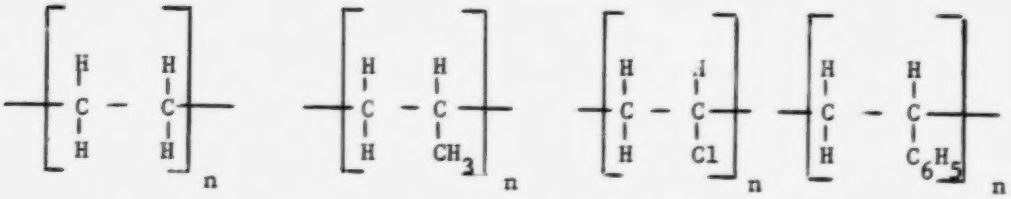
Because a plastic is made up of a mixture of materials with different melting points and physical properties, it does not usually have a clearly defined melting point and can exhibit different physical properties depending on the actual make-up of the mixture of molecules. Thus, two materials, both truly polyethylenes, can have differing physical properties based on differences in the molecular-weight distribution of the individual molecules making up the particular polyethylene. One polyethylene can be composed of mostly low-molecular-weight molecules and another mostly high-molecular-weight ones. These differences can grossly affect the physical properties of the plastic item and its ease of manufacture. High-molecular-weight polymers tend to be tougher and more chemically resistant than low-molecular-weight polymers.



Ethylene

Polyethylene

Figure 1. Interchain forces. Polyethylene a polymer made from ethylene has high strength because valence bonds (indicated by solid lines) have been established between the former ethylene molecules.



Polyethylene

Polypropylene

Polyvinylchloride

Polystyrene

Figure 2. Structure of important commercial polymers. The sub-script "n" denotes the number of repeating monomer units in the polymer.

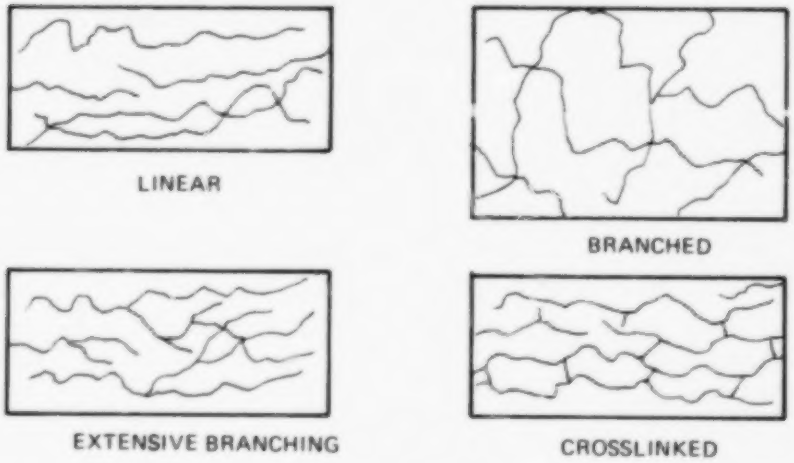
The distribution of molecules of different chain lengths has a significant but somewhat lesser effect than molecular weight on the properties of polymers. In general, as the molecular weight distribution widens, tensile strength and toughness decrease. On the other hand, the resistance of the plastic melt to flow is reduced, and the strength of the plastic while in the molten state is increased. Both of these properties are important in processing, which is the process of converting a polymer to an end plastic product (see section ''Processing'').

Molecular Shape

In addition to the size of molecules and the distribution of molecules of different sizes in a polymer mass, the shapes or structures of individual polymer molecules also play a major role in determining the physical properties of the plastic product. Polymer molecules can be linear, branched, or crosslinked (Figure 3). The properties of the branched type lie between those of the two extremes. It partakes of linear properties when slightly branched, and becomes more closely like the crosslinked polymer when the complexity of branching increases.

Linear and branched polymers are referred to as thermoplastics. These polymers when heated soften and can be shaped if pressure is applied. Most significantly, they can be reheated and reformed repeatedly, which is essential if the plastic is to be recycled. Common examples of thermoplastics are polyethylene, polystyrene, PVC, and polypropylene, whose structures were indicated in 2. On the other hand, the crosslinked structures, where the individual chain segments are chemically attached to one another, soften and are shaped only during the first heating cycle. They change chemically during this heat and pressure cycle to become intractable and insoluble and, therefore, cannot be reformed repeatedly in a recycling process. This type of material is referred to as a thermosetting plastic, and the process of crosslinking these polymers is called curing. Some examples of this type are the phenolic or urea-formaldenyde polymers.

The effect of branching on the properties of a polymer depends on whether the polymer is below or above its melting point. Below the melting point, branches along the polymer chain can reduce the tendency of the polymer to crystallize (see section below), if the particular polymer can exist in a crystalline form. For example, linear polyethylene has a high degree of crystallinity; branches can reduce the crystallinity from 90 percent to 50 percent. Above the melting point, branching can affect the flow of the molten plastic--but the effect is not always predictable. The melting temperature and its range is substantially affected by both the amount and randomness of branching. Typically, branched polyethylenes have a lower melt viscosity than the linear variety, if the molecular-weight range is the same.



LINEAR

BRANCHED

EXTENSIVE BRANCHING

CROSSLINKED

Figure 3. Structure of polymers, Polymer molecules can be linear, branched or crosslinked.

Crystallinity

Many polymers are partially but never completely crystalline. Typical crystalline polymers are those whose molecules are chemically and geometrically regular in structure, such as polyethylene and polypropylene. Commercial polystyrene and polyvinylchloride are examples of essentially non-crystalline polymers.

Molecules of potentially crystalline polymers have segments which can form three-dimensionally ordered arrays exhibiting inter- or intramolecular spacings (Figure 4). These crystalline regions or crystallites are very small--usually no more than a few hundred Angstrom units wide. Thus, polymer chains pass successively through several crystalline and amorphous (non-crystalline) regions. Crystallinity can vary from 5 to 95 percent of the total volume.

The crystallization of polymers in many ways resembles the crystallization of a low-molecular-weight substance such as sugar. As one cools the polymer melt, the rate of crystallization increases as the temperature is lowered below the crystalline melting point, reaches a maximum, and then drops off as the mobility of the molecules decreases with the decreasing temperature. Significantly, the melt of a crystallizable polymer may be quenched (cooled rapidly) to a temperature below its melting point, and thereby freeze in a disordered amorphous structure. If the molecules of this polymer are then kept at a temperature where they have some mobility (for example, at temperatures just below the crystalline melting point), crystallinity will eventually develop.

The crystalline melting point is a very important property of a polymer. It sets the maximum use temperature of any plastic item. Melting of the crystallites usually occurs over a range of temperatures, due to the variation in degree of perfection of the crystalline regions of the polymer. Under the normal molding conditions required to process a plastic the plastic has to be heated above this crystalline melting temperature.

Crystallinity is responsible for much of the tensile strength of polymers such as polyethylene. When a polymer crystallizes, the molecules are pushed together; thus, the weak intermolecular forces become more effective, and the strength of the plastic is increased (refer to section "Interchain Forces"). A complicating factor in this relationship of physical properties to crystallinity is that the size of the crystallites, as well as the total amount of crystallinity affect physical properties. Large crystalline aggregates (crystallites) stiffen the plastic and cause brittleness. On the other hand, very high-molecular-weight crystalline polymers are more flexible, because long polymer chains tend to limit the amount of crystallinity and the size of the crystalline region. It is the crystallites, by the way, which are responsible for the haze or translucency of many plastics.

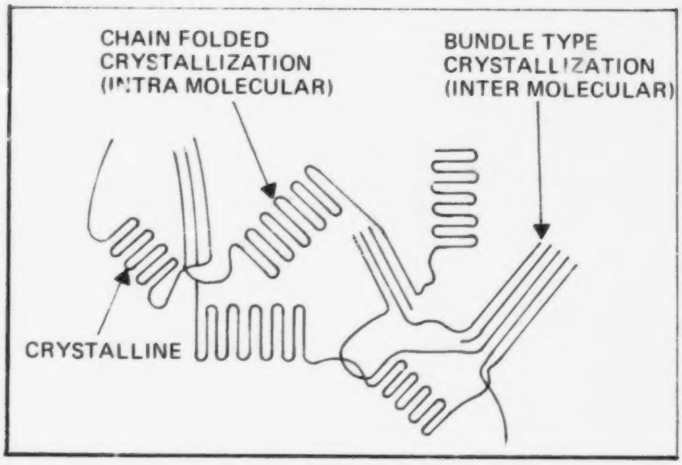

CHAIN FOLDED
CRYSTALLIZATION
(INTRA MOLECULAR)
BUNDLE TYPE
CRYSTALLIZATION
(INTER MOLECULAR)
CRYSTALLINE

Figure 4. Crystallinity in polymers. Molecules of potentially crystalline polymers have segments which can form three dimensionally ordered arrays exhibiting inter-or intra-molecular spacing.

Orientation

When a polymer is crystallized in the absence of external forces, the crystallites tend to form in a random fashion. However, if this crystalline polymer is subjected to an external stress, the crystallites become oriented with the polymer chains aligned in the direction of the applied stress. This effect is known as orientation.

Orientation is not limited to crystalline plastics. Virtually any thermoplastic material can be oriented. For example, polystyrene, which is not crystalline, undergoes considerable molecular orientation when subjected to stresses at temperatures near its softening point. This orientation, which is often seen in injection-molded pieces (see discussion below) is accompanied by the development of enhanced strength properties only in the direction of stress.

In the case of crystalline materials, the degree of crystallinity general does not change during orientation, if the crystallinity was previously well developed. Only the arrangement of the crystallites undergoes change. If the polymer was amorphous or only partially crystallized before drawing, crystallinity is likely to increase during cold drawing. Cold drawing is the process of orienting a polymer below its crystalline melting point.

There are two types of orientation--uniaxial and biaxial. As the name implies, in uniaxial orientation the polymer chains are aligned in one direction and, as noted above, this produces maximum strength in one direction also. The tensile strength of nylon (a crystalline polymer), for example, can be increased from 10,000 psi to over 80,000 psi, merely by drawing. Biaxial or planar orientation occurs when a film or sheet is drawn in two directions. Commonly the two axes are at right angles to one another. The tensile strength and modulus (stiffness) are increased in the two directions of pull. If desired, biaxial orientation can be balanced, so that the product has nearly the same strength properties from any direction.

Glass-Transition Temperature

Another characteristic property associated with polymers is the glass-transition temperature. As the polymer is warmed through this temperature, its properties change from a relatively hard, brittle, and glassy material into a softer, more flexible, and rubbery substance. It is the chemical makeup of a polymer molecule, in particular the size and geometry of the atoms or groups of atoms in the polymer chain that influences the glass-transition temperature. Thus, polystyrene, which has a bulky aromatic group along the polymer chain (see Figure 2), has a glass-transition temperature of about 85 C. In contrast, polyethylene with a flexible polymer chain particularly the linear variety, has a glass-transition temperature of -120 C. The glass-transition and melting temperatures for the important commercial plastics vary from -120 to 327 C (Table 1).

Glass transitions are associated with the amorphous phase of polymers. Therefore, their effect is greatest for completely amorphous polymers. Thus, as the Table illustrates, though the glass-transition temperature of the crystalline linear polyethylene is -120 C, it is the crystalline melting point of 135 C that affects use temperature. Another practical consequence of the glass-transition temperature is that plastics heated above this temperature lose their mechanical strength and rigidity (assuming a high concentration of amorphous material). Obviously, this is a very important use property of any plastic material.

Glass-transition temperatures and brittle temperatures are related. If a plastic sample survives a rapid impact, such as a hammer blow, at a particular temperature, it is judged to be above its brittle temperature. The brittle temperature is normally slightly higher than the glass-transition temperature.

Copolymers

As discussed above, the simple substitution of a single hydrogen atom along a polymer chain with another atom or chemical group (groups of atoms) can cause a drastic change in the polymer's properties. For example, polyethylene is translucent, flexible, and crystalline; whereas polystyrene, in which an aromatic group has been substituted for some of the hydrogen atoms along the polyethylene chain, is transparent, brittle, and amorphous. But it is also possible to change the chemical composition of the polymer by mixing the types of structural groups or basic repeating units (monomers) within the chain of a polymer. This is done by a process called copolymerization. For example, two monomers, styrene and acrylonitrile can be polymerized to form a styrene-acrylonitrile copolymer.

Not only can one vary the monomers used to form copolymers, but the relative amounts of each monomer used in the polymerization reaction also may be varied to produce literally an unlimited number of possible permutations and combinations of types and amounts of monomer units along a polymer chain.

Still another variation is possible in copolymerization. For example, in the preparation of a styrene-acrylonitrile copolymer, one can react a good portion of the acrylonitrile first, and then add the styrene in a subsequent step. Thus, even though two styrene-acrylonitrile copolymers contain the same amount of styrene and acrylonitrile, they may have different polymeric structures and different physical properties. The ability to copolymerize different monomers in different amounts and in different ways has given rise to the concept of ''tailormaking'' plastic materials.

TABLE 1

GLASS TRANSITION TEMPERATURES OF COMMON PLASTICS

Polymer	Tg (C)	Crystalline melting point or softening point (C)
Polyethylene-high density	-120	135
Polyethylene-low density	-25	98
Polyoxymethylene	-50	185
Polyvinylfluoride ("Tedlar")	-20	195
Polypropylene	0 to -20	175
Polyvinylidene chloride ("Saran")	-17	195
Polyvinyl acetate	29	up to 175
Polyhexamethylene adipamide (Nylon)	50	250
Polyethylene terephthalate ("Mylar")	69	255
Polystyrene	80-100(85)	105 - 110
Polyvinyl chloride		
No plasticizer	105	up to 212
15 percent plasticizer	60	
Cellulose acetate	70-120	up to 300
Polymethyl methacrylate	105	160
Polytetrafluoroethylene ("Teflon")	126	327
Polycarbonate	150	230

GENERAL PROPERTIES OF PLASTICS

In summary, the properties of a plastic are a result of the combined properties of all its polymer molecules: their different sizes, the distribution of their sizes, their chemical structure and shape, their ability to form crystallites, etc. In addition to the changes which may be made in these properties of a polymer, the properties can be radically altered by mixing it with various additives that are typically non-polymeric. In fact, some polymers are worthless to the manufacturer, if additives are not used to modify them. PVC is often mixed with semi-solvents called plasticizers to soften it to make flexible products, and many thermosetting polymers are brittle with low impact resistance; they must be mixed with a filler to make them usable.

In commercial practice, the number of different types of additives and fillers that are mixed with a polymer is very large. Thus, the technology of plastic compounds is extremely complex. Additives are mixed with the polymer not only to improve processing characteristics during manufacture but often to impart desirable properties to the final object.

Before discussing the extensive technology of additives, we will review the important properties of plastic compositions related to their end-use application. In this section we will introduce some of the properties that make plastics useful, whether a steering wheel or a refuse bag.

Appearance

Most commercial plastics are waterwhite and, if desired, they can be colored very easily. Many colors are possible and many are widely used, they can be bright, pastel, metallic, etc. In contrast to other materials, the color and finish of plastic materials can be relatively permanent; they need not depend on special surface coatings. Typically, opaque colored plastic items are obtained by incorporating pigments during one of the stages of manufacture. Many plastics also can be colored by the use of soluble dyes to produce transparent colored materials. Thus, plastics are usually colored through and through.

The high clarity of certain plastics is a very important asset. For example, polymethylmethacrylate (Plexiglass) rivals optical glass in clearness and appearance. Similarly, PVC, and some of the newer plastic compositions have sufficient clarity that they can be used as a substitute for glass in the production of bottles.

Exposure to outdoor weathering conditions may have a marked effect on the clarity or color of plastic materials. Alternate exposure to strong sunlight and moisture is particularly bad, although there is a wide difference in the resistance of various plastics toward weathering. The general effect of weathering is a darkening and/or a decrease in transparency of the plastic item (section ‘‘Ultraviolet Stabilizers’’).

Hardness

Hardness is related to the glass-transition temperature and the degree of crystallinity. According to the discussion in the previous section, if a hard material is required one should select a polymer that has a use temperature considerably below its glass-transition temperature. If the polymer is crystalline, one would also select the polymer having the highest degree of crystallinity.

Scratch resistance and resistance to penetration are related to hardness. Unfortunately, in the case of most plastic materials their surface hardness is low relative to glass, ceramics, or metals. One salvaging feature is that deep scratches on opaque colored plastic articles are not easily seen because the bottom of a gouge has the same color as the surface.

Density

Plastics have a definite weight advantage over practically all materials of construction except wood. The specific gravities (ratio of the weight of a given volume of material to a similar volume of water at a temperature of 4 C) of most plastics vary from about 0.90 to 2.0, and the majority are in the range of 0.9 to 1.4. Thus, plastics are considerably lighter than magnesium which has a specific gravity of 1.7. As a result, plastics are a prime candidate where weight is a consideration in the end application.

Another important advantage of the low density is economics. Like most materials, plastics are priced and sold on a weight basis but practically all applications are based on volume. For this reason, cost comparisons with metals cannot be made on the basis of cost per pound. Densities must be considered, and the cost per unit of volume calculated.

Mechanical Properties

To a large extent, polymers are useful because of their mechanical properties. It is the combined characteristics of high strength and low weight that have made plastic materials an important factor in the last decade. Plastics can exhibit a wide variety of mechanical properties varying from gel-like substances to flexible and semi-rigid structures to hard tough forms and finally to hard brittle materials. Plastics are also more sensitive to environment (external conditions of service) than most materials. This is particularly true of temperature; but moisture, light, and weathering may have a profound effect on properties. Most plastics require special additives to avoid this type of problem, and these will be discussed in the next section.

Tensile Strength. Tensile strength is one of the most commonly measured physical properties. It may be defined as the stress expressed in pounds per square inch necessary to stretch a strip of material being tested to its breaking point. Tensile strength of plastics range from 1,000 to 13,000 psi. For comparison, the tensile strengths of aluminum and different steels are 30,000 to 40,000 psi and 80,000 to 330,000 psi, respectively.

The tensile strength of plastics may be greatly enhanced by incorporating relatively large amounts of a filler. This effect varies with the chemical and physical nature of the filler. Tensile strength values also may be affected by the manufacturing method used to form an end plastic item; for example, the effects of orientation.

Temperature has a marked effect on the mechanical properties of plastics, and the tensile strength in particular. Although other materials are affected in a similar manner, the range of temperatures within which changes occur is usually much less for plastics than for other substances. The way in which temperature affects the ultimate strength depends on the plastic material (Figure 5). In general, an increase in temperature causes a rapid decrease in ultimate strength. The modulus of elasticity, which reflects the stiffness of a plastic, is similarly affected, while the ultimate elongation increases. Thermosetting materials are less affected by temperature than thermoplastics.

Elongation. The increase in length of a measured plastic strip when stretched to its breaking point, expressed as a percentage of the original length is known as the elongation. Generally, the values of elongation and tensile strength are obtained during the same test and are of equal importance in expressing the behavior of a plastic material. In general, materials that are crosslinked or thermoset have low elongation values, whereas thermoplastics are capable of considerably greater elongation.

Compressive Strength. This is another property that is allied to tensile strength. As the name implies, it involves compression rather

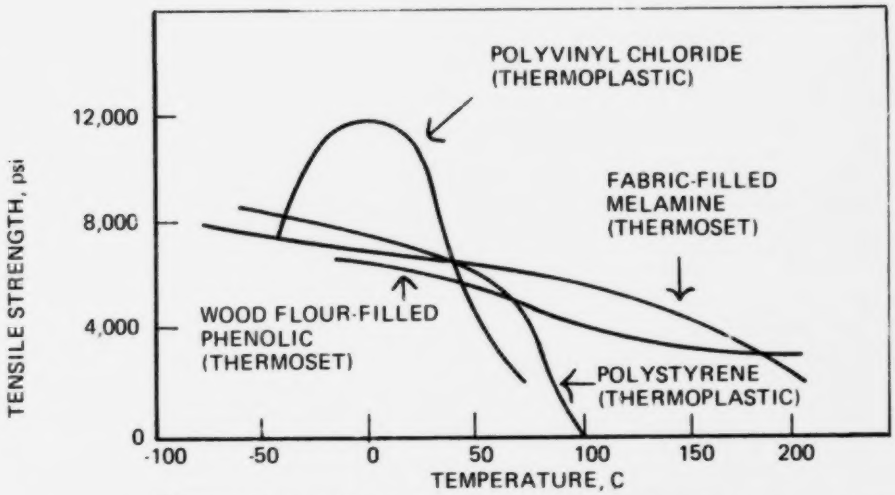


Figure 5. Effect of temperature on polymers. Thermosetting materials are less affected by temperature than thermoplastics.

than stretching and is determined by measuring the compression load in pounds at the breaking point divided by the cross-sectional area of the surface affected. The compressive strength of typical plastics range from 5,000 to 80,000 psi. Most plastics, however, have compressive strength values below 40,000 psi.

Flexural and Fatigue Strength. Still another important property related to strength is flexural strength. It is a measure of the resistance of a strip to breaking as it is bent across its main axis. Typically, it is measured by determining the force required to cause rupture of a horizontally supported bar.

The property often correlated with flexural strength is fatigue strength resistance. This is determined by measuring the resistance of the plastic specimen to repeated flexing through a known arc.

Impact Resistance. Resistance of a plastic to sudden shock or impact is a necessary condition for many applications. This property, known as impact resistance, is usually measured either by the Izod or the Charpy method. These methods compare the free swing of a pendulum and the swing involved in breaking a notched test specimen. The difference in height to which the pendulum rises when swinging freely, and after breaking the test strip, is a measure of the energy absorbed in the rupture. The values are expressed in foot-pounds per inch of notch.

Impact resistance is commonly accepted as a measure of the toughness of a material. Materials having high tensile strength and moderate elongation will usually have good impact strength; flexible materials, although weak, also exhibit excellent impact strength. As mentioned above, temperature can markedly affect the elongation of a plastic material. Typically, an increase in temperature results in an increase in impact resistance. Conversely, low temperatures impart brittleness; therefore, plastics must be selected carefully for an end use, if they are likely to encounter very low temperatures. Generally, as the size of the polymer molecule increases, impact resistance also increases.

Creep. One of the most serious limitations plastics have for many structural applications is that they distort under stress. These distortions can be classified as either ‘‘cold flow’’ or ‘‘creep.’’ Cold flow describes a continuous and constant rate of deformation at normal temperatures under small stresses. Creep is similar; however, the rate of deformation in this case may change with time and the extensibility of the plastic material.

Stresses and the resulting deformation may occur in structural parts not ordinarily considered to be highly stressed; for example, rotating blades resist centrifugal stresses, materials around metal inserts are also subject to stresses resulting from differential contraction, and stresses even result from differential water absorption of various materials. These types of plastic deformation are expressed in terms of the percent distortion based on the original dimensions that are not recoverable in a specified period of time. Often creep values are reported after 1,000 hours of test. The creep properties of plastic materials are greatly affected by changes in temperature and relative humidity. As expected, thermosets exhibit much better creep properties than do thermoplastics. To assist in overcoming the deformation under continued load, metal inserts are sometimes placed in plastic parts.

Dimensional Stability. In most applications dimensional stability is extremely important. In the manufacture of a plastic item the material often exhibits shrinkage within a short time after removal from the mold. This shrinkage is relatively constant and normally allowances for it can be made. However, this property causes difficulty when parts require very close dimensional tolerances.

The dimensional stability of a plastic material also may depend on the environment to which it is subjected and its expected service life. For example, plasticizers (the additive used to make plastic compositions softer and more flexible) often evaporate from a plastic material as it ages. This loss can cause cracking, warping, and shrinkage, as often observed in old automobile upholstery. Moisture or a change in the moisture content of the air, is a frequent cause of dimensional change in plastic materials.

Thermal Properties

The important thermal properties of plastics are their conductivity, specific heat, heat-distortion temperature, heat resistance, flammability, and coefficients of expansion. Plastics have a low thermal conductivity. This makes them ideal for certain applications such as electrical heating devices, handles on pots and pans, etc. However, as a corollary property, generally more heat is required to heat plastic materials as compared to metals.

The utility of a plastic material is often limited by its heat resistance. Not only is there a wide variation in the heat resistance of different types of plastics, but within those types wide differences also occur. The maximum continuous service temperature of various plastic materials can vary from 100 F to 500 F (Table 2).

In the typical heat distortion test, samples under stress (66 or 264 psi) are gradually heated until a deflection of 0.010 in. is noted at the center of the sample where the stress is applied. These tests only indicate heat resistance over a short period of time. The results cannot be used to predict creep over extended periods.

TABLE 2

COMPARATIVE HEAT RESISTANCE OF PLASTIC MATERIALS*

	Type of plastic	Maximum continuous service temperature, F
1.	Teflon (polytetrafluoroethylene)	400-500
2.	Silicone resins	350-500
3.	Heat-resistant phenolics	350-500
4.	Polytrifluorochloroethylene	390
5.	Polyesters	300-450
6.	General-purpose phenolics	300-350
7.	Nylon	300
8.	Epoxies	250-500
9.	Laminated phenolics, asbestos base	250-300
10.	Polyethylene, low pressure	260
11.	Melamine formaldehyde	210-300
12.	Laminated phenolics, asbestos base	250-300
13.	Laminated phenolics, cotton-fabric base	225-250
14.	Laminated phenolics, paper base	225-250
15.	Cast phenolics	160-250
16.	Polyethylene, high pressure	210-230
17.	Saran (polyvinylidene chloride)	160-200
18.	Urea-formaldehyde	170
19.	Polymethyl methacrylate	155-185
20.	Polystyrene	150-185
21.	Cellulose acetate-butyrate	140-220
22.	Cellulose acetate	140-220
23.	Ethyl cellulose	140-220
24.	Vinyl chloride copolymers	150-175

*The order within this table can be altered because special heat-resistant grades are available.

Certain polymeric materials, for example cellulose nitrate, are very flammable, while others such as the phenolics (a thermoset) burn with difficulty or not at all. The flammability of polymers depends on the chemical makeup of the polymer chain. For example, polymers that contain a high proportion of chlorine such as PVC burn with difficulty. Generally, plastics are difficult to ignite and require heat from another source to make them continue to burn. Burning rates of plastic articles vary depending on the presence and quantities of other materials in the article and on the ratio of surface to mass. Thus, thin foils and films burn much more rapidly than heavy or thick sections.

Electrical Properties

Although plastics in general possess excellent insulating characteristics, considerable care is required in manufacturing plastic insulators. All moisture has to be excluded. Typically, those plastics that have the greatest resistance to moisture also show the highest degree of usefulness as insulators. In the preparation of a plastic compound for electrical applications, careful selection of the additives (see discussion below) is necessary. Almost all additives detract from the electrical properties that can be obtained with the polymer alone.

Chemical Resistance

The resistance of plastics to various chemicals varies widely not only from polymer to polymer but in some instances, within the different available grades of a single type. A few polymers such as polytetrafluoroethylene (Teflon) are not attacked even by the most corrosive chemicals or powerful solvents. Chemical resistance is very important in numerous commercial applications, especially in industrial processing.

Resistance to solvents depends on many factors already discussed. Thus, the type of polymer chain, side groups, molecular weight, secondary forces between chains, rigidity of the chains, the extent of crosslinking--all may have an effect on solvent resistance. Generally, increasing the molecular size or the amount of crosslinking improves the chemical resistance of a plastic. Polymers whose chemical structure makes them miscible with water, for example polyvinylalcohol, are usually not affected by hydrocarbon solvents, oils, and greases. Furthermore, because solubility generally increases with temperature, resistance of plastics to solvents is decreased at elevated temperatures.

Flow Properties

The softening behavior of polymers is of considerable practical importance. Most plastic articles go through the softening stage during their manufacture, as in molding. The melt viscosity of a polymeric material depends on the size of the polymer molecules. When the molecules are short, less entanglement occurs for resistance to flow is normally due to the friction of one polymer chain segment moving past its neighbors. Thus, melt viscosity is proportional to the molecular weight of a polymer. As the chain length increases, the number of entanglements per molecule also increases and, if the entanglements become permanent, a thermoset forms and all flow ceases.

Melt viscosity of polymers is usually measured in terms of a quantity called the melt index. This index corresponds to the number of grams of polymer flowing through a standard orifice in a given time at a standard pressure and temperature.

In many manufacturing processes, it is convenient to have a plastic material that flows very readily. This is called a high melt-index plastic. However, the use of high melt-index materials entails certain penalties in other physical properties, such as a decrease in tensile and impact strength, and environmental resistance.

ADDITIVES

One of the important advantages of using a polymer to manufacture an end item is that additives can be used to emphasize particular properties not inherent in the base polymer. This process of incorporating additives into a polymer is called compounding, and the mechanics of this operation will be discussed in a later section. In this report ''polymer'' describes the material that is obtained from the reaction vessel free of auxiliary additives, and ''compound'' describes the composition that is obtained when the polymer is mixed with additive or filler. The term ''resin,'' which is commonly used by the industry, is a good general term signifying polymer or compound. By approximate compounding polymers can be made resistant to oxidation, the effects of ultraviolet radiation, and environmental degradation in general. Other additives are used to modify a molding compound to provide melt viscosity control, improve process lubrication, assist the mold release of a finished part, prevent slip or adhesion of plastic film, or improve the properties of a filled or reinforced molding compound.

Antioxidants

The discussion above has often touched on the sensitivity of certain polymers to environmental conditions. Oxidation is a very important factor in the weathering of polymers. Polymers are subject to oxidation during manufacture and use, and oxidation can alter the polymer structure and degrade the physical and chemical properties of the fabricated plastic product. Oxidation also can degrade electrical properties and increase the polymer's susceptibility to photodegradation. Oxidation reactions include chain scission that reduces the molecular weight of the polymer and/or chain branching or crosslinking. These reactions can cause embrittlement, loss of tensile strength and elongation, color formation or darkening, odor development, and changes in the polymer's melt viscosity.

To retard oxidation, antioxidants are added to the polymer at concentration levels usually less than 1 percent. Chemically these antioxidants are principally phenols, amines, phosphites, and various sulfur compounds. They are effective because they can either trap the intermediate species formed during the oxidation, or they can decompose peroxides that often form during this process.

Antioxidants selected for a given application should be compatible with the polymer at the effective use concentration and should have sufficient thermal stability to survive the temperatures of manufacture and service. Furthermore, the antioxidant should not contribute color either initially or in aging and should not interact with other additives in the polymer. In many instances, additives must satisfy Federal requirements (FDA) for use in packaging materials in contact with food. This requirement can affect the recyclability of plastics used in this application.

Antistatic Agents

Plastics are particularly subject to static build-up. Static electricity often accumulates on a plastic surface during manufacture, as in the manufacture of polyethylene bottles, polystyrene cups, PVC records or polystyrene cabinets. Static electricity can accumulate not only during manufacture but also during packaging and in transit. During plant manufacture, static charges can cause dust attraction, and the plastic articles must be cleaned before being shipped. At the consumer level, plastic products without the additive collect dust and look dirty.

The static charge can be dissipated through the use of internal or external antistatic agents. External agents give short-time protection, because they are easily removed by wear and exposure; whereas internal agents are more permanent. Typically, the latter are incorporated in the compound before molding.

The four basic types of antistatic agents are: (1) amine derivatives; (2) quaternary ammonium salts; (3) phosphate esters; (4) polyethylene glycol esters. External agents are usually applied at 0.5 to 2 percent concentrations, and internal agents at concentrations ranging from 0.1 to 1 percent. Over the past five years, FDA-approved internal antistatic agents have slowly gained acceptance in various food packaging applications. Most of these additives were used in rigid plastic containers to give the container ‘‘eye appeal.’’

Colorants

There are three basic types of colorants: (1) dyes; (2) organic and inorganic pigments; (3) colorants for special effects. Dyes have excellent brightness but limited light stability and poor resistance to most processing temperatures, particularly above 375 F. Also, they are usually expensive. Most frequently they are employed to produce brilliant and transparent colors in clear plastics such as crystal polystyrene, and sometimes are used in the manufacture of colored film. Organic pigments, which are insoluble forms of the dyes, remain distinct solids when suspended in a polymer matrix. They have excellent light stability, but not as good as the best inorganics. The slight solubility of some of these organic pigments in certain solvents usually causes problems. On the other hand, inorganic pigments are completely insoluble in solvents. These are usually special salts or oxides of metals that have very good hiding power and excellent heat and light stability. The high tonnage member of this group is titanium dioxide, which has excellent whiteness, good opacity, and stability. For special effects pigments such as aluminum and copper flakes are included. Brilliant or specular reflection is achieved with these pigments. They have good hiding power and tinting strength and are excellent in mixtures with other pigments.

Colorants are generally supplied either as dry colors or color concentrates. Dry colors are pigment blends that contain no polymer, but may have wetting agents or lubricants. The plastics manufacturer adds dry colors to his polymer to make a colored product. The cost of these colors is relatively low, but dust and contamination are possible problems. On the other hand, color concentrates, which normally come as pellets or granules, are essentially dust-free. These concentrates contain a high loading of pigment or dye dispersed in a polymer. Concentrates are then diluted with polymer at a ratio of from 100:1 to 3:1 by the plastics manufacturer to give an evenly colored product. Dispersion is of key importance in using any of these colorants, because poor dispersion means weak hiding power and poor tinting strength.

In selecting colorants for a given polymer system the processing temperature of the polymer is of paramount consideration. Nearly all commercial pigments and dyes will survive short exposures up to 375 F without color change or degradation. Certain colorants will perform well up to 450 F but very few retain their properties above 550 F. Some of the colorants cannot be used with particular polymers; for example, colorants with free copper, zinc, manganese, and magnesium cannot be used in PVC because they promote degradation.

Most importantly, the application dictates the type of colorant. Acrylics, for example, need very light-fast colorants because they find their major use outdoors; and impact polystyrenes must have well dispersed pigments to prevent loss of impact resistance.

Fillers

Commonly fillers are divided into three classes: (1) extenders, which are low cost fillers; (2) carriers, which serve some function in addition to economy; (3) reinforcing fillers, which improve the strength properties of plastics. Although some fillers are inert, there is mounting evidence that strong attraction exists between many fillers and the atoms along the polymer chain. While these forces may be weak, they are additive and thus become more significant as the polymer-chain-length increases. Fillers tend to reduce crystallinity and solubility, and increase the glass-transition temperature, hardness, and stiffness of compounds. The principal types of fillers can be classified into ten groups (Table 3). Fillers vary widely in availability, cost, and composition as well as in physical, electrical, and chemical properties. The filler content may vary from over 97 percent in some molding processes to a few percent in carbon-filled polyethylene. However, it is customary to use at least 60 percent polymer in most composites to assure physical properties.

A summary of the effect of these different fillers on the physical properties of plastics shows that some are appropriate for thermoplastics and others for thermosets (Table 4). Silica products, for example, are added to polymethylmethacrylate castings to improve dielectric properties and resistance to heat and moisture; and the addition of zinc oxide to polypropylene provides excellent weathering resistance. Carbon black, which is used widely in plastics, decreases the photo-oxidation of polymers such as polyethylene, and increases the tensile strength, heat resistance, and hardness of polymers such as PVC.

Fibers

The use of various fibers and, in particular, glass fiber as a reinforcing filler in plastics is a fast-growing market today. Over 1 billion lbs of glass-fiber reinforced plastics were produced in 1970. Five principal fibers are used with polymers (Table 5).

Fibrous glass continues to be the most widely used reinforcing agent for plastics and has been added to every commercially available thermosetting and thermoplastic polymer. Many of the properties of bulk glass are also found in fibers with some differences. Glass in fibrous form has greater mechanical strength, but because of the very high surface area of the fiber, chemical resistance is decreased. Regardless of filament diameter,

TABLE 3

TYPES OF FILLERS FOR POLYMERS

A. Silica products
  1. Minerals
    (a) Sand
    (b) Quartz
    (c) Novaculite
    (d) Tripoli
    (e) Diatomaceous earth
  2. Synthetic amorphous silica
    (a) Wet process silica
    (b) Fumed colloidal silica
    (c) Silica aerogel

B. Silicates
  1. Minerals
    (a) Kaolinite (China clay)
    (b) Mica
    (c) Nepheline syenite
    (d) Talc
    (e) Wollastonite
    (f) Asbestos
  2. Synthetic products
    (a) Calcium silicates
    (b) Aluminum silicate

C. Glass
  1. Glass flakes
  2. Hollow glass spheres
  3. Solid glass spheres
  4. Cellular glass nodules
  5. Glass granules

D. Calcium carbonate
  1. Chalk
  2. Limestone
  3. Precipitated calcium carbonate

E. Metallic oxides
  1. Zinc oxide
  2. Aluminum
  3. Magnesia
  4. Titania
  5. Beryllium oxide

F. Other inorganic compounds
  1. Barium sulfate
  2. Silicon carbide
  3. Molybdenum disulfide
  4. Barium ferrite

G. Metal powders
  1. Aluminum
  2. Bronze
  3. Lead
  4. Stainless steel
  5. Zinc

H. Carbon
  1. Carbon black
    (a) Channel black
    (b) Furnace black
  2. Ground petroleum coke
  3. Pyrolyzed products

I. Cellulosic fillers
  1. Wood flour
  2. Shell flour

J. Comminuted polymers

TABLE 4

EFFECT OF FILLERS OR REINFORCEMENTS ON THE PROPERTY OF PLASTICS*

Filler or reinforcement	Chemical resistance	Heat resistance	Electrical insulation	Impact strength	Tensile strength	Dimensional stability	Stiffness	Hardness	Lubricity	Electrical conductivity	Thermal conductivity	Moisture resistance	Processability	Recommended for use in†
Alumina tabular	●	●				●								S/P
Alumina trihydrate, fine particle			●				●					●	●	P
Aluminum powder										●	●			S
Asbestos	●	●	●	●		●	●	●						S/P
Bronze							●	●		●	●			S
Calcium carbonate		●				●	●	●					●	S/P
Calcium metasilicate	●	●				●	●	●				●		S
Calcium silicate		●				●	●	●						S
Carbon black		●				●	●			●	●		●	S/P
Carbon fiber										●	●			S
Cellulose				●	●	●	●	●						S/P
Alpha cellulose			●		●	●								S
Coal, powdered	●											●		S
Cotton (macerated/chopped fibers)			●	●	●	●	●	●						S
Fibrous glass	●	●	●	●	●	●	●	●				●		S/P
Fir bark													●	S
Graphite	●				●	●	●	●	●	●	●			S/P
Jute				●			●							S
Kaolin	●	●				●	●	●	●			●	●	S/P
Kaolin (calcined)	●	●	●			●	●	●				●	●	S/P
Mica	●	●	●			●	●	●	●			●		S/P
Molybdenum disulphide							●	●	●			●	●	P
Nylon (macerated/chopped fibers)	●	●	●	●	●	●	●	●	●				●	S/P
Orlon	●	●	●	●	●	●	●	●				●	●	S/P
Rayon			●	●	●	●	●	●						S
Silica, amorphous			●									●	●	S/P
Sisal fibers	●			●	●	●	●	●				●		S/P
TFE-fluorocarbon						●	●	●	●					S/P
Talc	●	●	●			●	●	●	●			●	●	S/P
Wood flour			●		●	●								S

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* Source: 1968 Modern Plastics Encyclopedia. New York, McGraw-Hill, Inc. p. 572.

† Symbols: P-in thermoplastics only; S-in thermosets only; S/P-in both thermoplastics and thermosets

TABLE 5

TYPES OF FIBROUS REINFORCEMENTS FOR POLYMERS

Cellulose fibers
1. Alpha cellulose
2. Pulp preforms
3. Cotton flock
4. Jute
5. Sisal
6. Rayon

Synthetic fibers
1. Polyamide
   (nylon)
2. Polyester
   (dacron)
3. Polyacrylonitrile Metallic fibers
   (dynel, orlon)
4. Polyvinyl alcohol Whiskers

Asbestos fibers

Carbon fibers

Fibrous glass
1. Filaments
2. Chopped strand
3. Reinforcing mat
4. Glass yarn
5. Glass fabric

fibers have tensile strengths in the range of 400,000 to 500,000 psi. Damage to filaments during normal manufacturing and usage reduces fiber strength, so that it seldom exceeds 300,000 psi tensile strength in commercial form; and in some fibrous glass reinforced thermosets, tensile strength runs as high as 250,000 psi.

Fibrous glass is used in a variety of forms such as chopped strands, continuous filament, milled fibers, yarns, woven fabrics, etc. Generally, glass loading in the 20 to 40 percent range are used with thermoplastics. Typically, the physical properties of a reinforced thermoplastic improve as the glass content increases. Orientation of glass fibers toward the direction of expected stress generally produces reinforced plastic parts having the greatest relative strength. Increasing the glass content also improves the ability of a plastic to bear stress. The less expensive forms of fibrous glass, such as chopped strand, are used to produce parts of lower glass content. Correspondingly, continuous roving and filament winding are used in plastic items of high glass content and yield products of extremely high strength.

Flame Retardants

As a result of recent government regulations, the overall growth rate for fire retardants in plastics is increasing. Many chemicals provide fire retardancy, and typical compounds are those containing one or more of the following--antimony, halogens, phosphorous, boron, or nitrogen. Often a combination of more than one of these additives is used for a given end use application.

Lubricants

In many manufacturing processes involving plastics a lubricant is considered an absolute necessity. The industry classified lubricants as either external or internal. The external lubricant normally is not compatible with the polymer and exudes to the surface of the melt, thereby reducing the friction between the polymer and the processing equipment. On the other hand, internal lubricants tend to reduce intermolecular friction within the polymeric mass, and normally they are miscible with the polymer.

Lubricants are used at concentration levels varying from 0.5 to 2 percent. They must be carefully selected in any given formulation if haze, blooming, and embrittlement are to be avoided. In some cases, other additives also can behave as lubricants and this effect has to be considered in the selection. Lubricants find use in PVC, polyolefins, polystyrene, phenolics, nylons, and other plastics. Compounds such as fatty acid esters and certain metal carboxylates have been used for this application.

Plasticizers

Plasticizers are usually high boiling organic liquids that are chemically and thermally stable, and used to modify the physical properties of polymers. In most applications they are used to aid in the various processing steps to make end products and to impart flexibility and softness to these products. Recalling the earlier discussion of polymers, plasticizers function by reducing the secondary forces between polymer chains. They separate these chains by selected solvation.

Many plastics such as nylon, polyethylene, polystyrene, do not require plasticizers; about 80 percent of all plasticizers consumed are used in PVC formulations. To operate effectively, plasticizers must be compatible with the polymer and the other additives. Depending on the end use, other important qualities needed of a plasticizer include resistance to soapy water extraction, resistance to extraction by solvents, low temperature flexibility, low volatility, and stain resistance.

Practical considerations of performance and cost severely limit the number of organic compounds that are useful as plasticizers. Esters, particularly diesters such as phthalates, are by far the most important class. The phthalates, di-2-ethylhexylphthalate (DOP) and di-isoctylphthalate (DIOP) dominate the field and are standards for the PVC industry because they impart a good overall balance of performance at low cost.

Other phthalates have specific end uses; for example, the linear variety prepared from straight chain alcohols have a good combination of low temperature properties and low volatility. Esters of other acids such as adipates and azelates are also used for their superior low temperature properties, and phosphate esters are especially valuable because they also can impart flame resistance.

Stabilizers

While stabilizers can help in the processing and end use applications of many polymers, their primary use is in PVC. Stabilizers are required to impart thermal stability to polymers during processing and thereby preserve their physical properties. Like other additives, stabilizers must be compatible with the polymer composition and must not exude to the surface of the finished product.

Because of the chemical structure of the PVC polymer chain, homopolymers and copolymers of PVC are subject to ‘‘thermal oxidative decomposition,’’ which involves dehydrochlorination, oxidation, chain scission and crosslinking. When dehydrochlorination occurs, the PVC molecular absorbs light, and the polymer color changes from white to yellow to red and finally black. Many metals catalyze this dehydrochlorination reaction. As hydrochloric acid evolves from the polymer chain in the presence of oxygen, scission occurs, and the molecular weight and melt viscosity of the polymer are reduced. In the final stage, the PVC also becomes crosslinked, and localized crosslinking can produce insoluble gels. All of these stages of decomposition lead to a deterioration of physical properties of the finished product.

The PVC stabilizer is effective because it can eliminate labile sites responsible for initiating dehydrochlorination, and it can act as an HCl scavenger, or it can serve as an antioxidant.

Stabilizers are usually organometallic compounds and the main ones are as follow: (1) Lead stabilizers--these are lead salts of acids. They are low in price, offer excellent electrical properties, and display good heat stability characteristics. However, they generally impart opacity to a PVC compound and tend to discolor rapidly under heat. (2) Barium cadmium stabilizers--these are usually blends of barium and cadmium soaps together with zinc soaps, organic phosphites, and antioxidants. These compounds provide PVC with good long term heat stability; however, these additives tend to degrade suddenly and produce failure with little or no warning. (3) Nitrogeneous stabilizers--these are based on dicyandiamide and/or melamine. They are very effective in vinyl asbestos formulations for floor tile. (4) Calcium zinc stabilizers--these are usually restricted to food grade applications because they offer relatively poor stabilization. They are often fortified with polyols and antioxidants, most of which are limited in use by FDA regulations. (5) Butyl tin stabilizers--these are either sulfur containing or sulfur free. The sulfur containing products are generally the most effective, but have odor and staining problems. The sulfur free products are generally used in vinyl copolymers. These tin compounds are the only products that fulfill all stabilization requirements of rigid PVC--clarity, compatibility, initial color hold, long term heat stability, melt viscosity control, blush characteristics, etc. They are widely used in molding, rigid PVC sheet, pipe fittings, and siding. (6) Octyl tin stabilizers--these are sanctioned by FDA for use in the manufacture of PVC articles for food packaging and food contact use. Specifically, they are used in PVC for packaging many products including vinegars, cooking oils, whiskeys, juices, olives, honey, peanut butter, mouthwashes, and various pharmaceuticals.

The stabilization requirements for PVC are dictated by the product application and the necessary manufacturing procedure. Table 6 lists the type of stabilizers recommended in specific product areas.

Ultraviolet Stabilizers

Plastics like many other organic materials are degraded by exposure to ultraviolet light, which is emitted by the sun. The degradation can

TABLE 6

PVC STABILIZERS USED FOR VARIOUS PRODUCT APPLICATIONS

Product application	Type of stabilizer
Blow molding	Tin
Calendering, flexible	Barium cadmium
Calendering, rigid	Tin
Electrical	Lead
Extrusion, flexible	Barium cadmium
Extrusion, rigid	Tin
Flooring, asbestos	Nitrogeneous
Flooring, homogeneous	Barium cadmium
Foam	Lead
Molding, flexible	Barium cadmium
Molding, rigid	Tin
Non-toxic, flexible	Calcium zinc
Non-toxic, rigid	Octyltin
Plastisol	Barium cadmium
Solution	Tin

lead to various changes such as discoloration, loss of gloss, reduction in electrical properties or lowered physical properties. Some polymers such as polymethylmethacrylate and PVC are very resistant to light degradation. Others, such as polypropylene, deteriorate very rapidly. The best way to control this type of degradation is through the use of UV stabilizers.

The stabilizers operate in the following two ways: (1) they may preferentially absorb most of the UV light, and dissipate the energy in a harmless manner; (2) they may remove the energy that the polymer has absorbed before chemical degradation can take place. Most of the common UV stabilizers are primarily absorbing agents. A few, particularly complexes of nickel or other heavy metals, act as energy transfer agents. Other types of UV stabilizers are benzophenones, benzotriazoles, substituted acrylates, and pigments such as carbon black and titanium oxide.

SELECTED POLYMERS

As was noted in the discussion of the structure of polymers, there are two major categories of plastics: thermoplastics and thermosets. The thermosets cannot be remelted; therefore, any recycling of these types of materials would be difficult, unless the product was used as a filler or pyrolyzed. On the other hand, the thermoplastics are easily remelted, and they can be converted from one form to another. For example, one can take scraps of flexible PVC sheet and, by appropriate processing, convert the material into a molded PVC item.

Because the primary objective of this study is recycling, we are concerned primarily with thermoplastics. Thermoplastics represent 80 percent of all plastics (Table 7). This percentage includes thermoplastic coatings and adhesives, but recycling of these materials is virtually impossible. Thus, excluding coatings and adhesives, the total percent of potentially recyclable thermoplastics is 75 percent of all plastics. Five thermoplastics, namely HDPE, LDPE, polypropylene, styrene polymers, and PVC represent 89 percent of all thermoplastics (excluding coatings and adhesives). The share of the market for each of these five thermoplastics is dominated by LDPE, PVC, and styrene polymers (Table 8). (Estimates of the future markets for these materials is discussed in the section ‘‘The Plastics Industry.’’)

Because of the dominance of these five thermoplastics, this study is, therefore, essentially restricted to these materials. The following sections include a description of the major features of each of these polymers--raw materials, manufacturing process, properties, and applications.

TABLE 7

PLASTICS PRODUCTION --1969*

Type	Pounds (billion)	% of Total plastics
All plastics	18.7	100
Thermoplastics	14.9	80
Thermosets	3.7	20
Thermoplastic coatings	0.8	4
Big 5 thermoplastics (excluding coatings) †	12.5	67
Thermoplastics (excluding coatings)	14.1	75

* Source: U.S. Tariff Commission

† HDPE, LDPE, Polypropylene, Polystyrene, PVC. Extrusion coatings are included in this category.

TABLE 8

PRODUCTION OF MAJOR THERMOPLASTICS--1969*

Type	Pounds (billion)	%
LDPE	3.88	30.0
HDPE	1.61	12.4
PVC	3.03	23.4
Styrene polymers	3.34	25.8
Polypropylene	1.09	8.4

*Source: U.S. Tariff Commission

Polyethylene

Polyethylene is the major plastic of commerce. Today it is available in compounds of widely different structures, as copolymers, in polymer mixtures, as filled compositions, and as crosslinkable products, etc. As a general class, they are noted for (1) outstanding dielectric properties; (2) chemical resistance to solvents; (3) toughness; (4) good barrier properties; (5) their relative adaptability to the various fabricating techniques used for processing plastics. Furthermore, these properties can be adjusted through a tailoring of the molecular structure and the incorporation of additives.

Raw Materials. Polyethylene is manufactured from a colorless and combustible gas called ethylene. Ethylene is not found in crude petroleum or in natural gas, it is available in off gases from refineries that crack petroleum stocks, and some is recovered from this source. Most ethylene in the U.S. is obtained from the pyrolysis of natural and refinery gases. Even heavier feedstocks can be used and pyrolysis of this stock is receiving more attention today. Special auxiliary purification procedures are frequently required to remove impurities in the ethylene used for the polymerization of polyethylene.

Manufacturing Process. Polyethylenes are classified according to two main types: low density (LDPE), which is usually branched chain; and high density (HDPE), which is predominantly linear. A range of properties is obtained by these processes (Figure 6).

Low Density Polyethylene. Most low density polyethylene is made at high pressures ranging from 15,000 to 50,000 psi using a free radical initiator such as a perioxide. Following the flow diagram for this process (Figure 7), the basic steps in the process are (1) compression of purified ethylene to a pressure of 15,000 to 40,000 psi or higher; (2) introduction of a free radical initiator at some stage of compression or in the reactor; (3) heating of the mixture to 100 or 200 C to initiate polymerization; (4) stepwise let down of the reaction mixture into separators with reduced pressures in order to separate the polymer and unreacted ethylene. Note that low molecular weight waxes and oils are recovered in this step. These are waste products and are usually disposed of by incineration or landfill and represent 0.2 percent of production. Finally (5), the molten polymer is extruded under sufficient pressure so that it is forced through a die and converted into pellet form (see section ''Extrusion''). The overall yield, on the average, is approximately 98 percent; more than one pass of the ethylene is required, and it is recycled in the process.

In this process, pressure, temperature, and type and concentration of the initiator are the most important factors which can be varied and balanced. The final product is normally tested for melt flow and density.

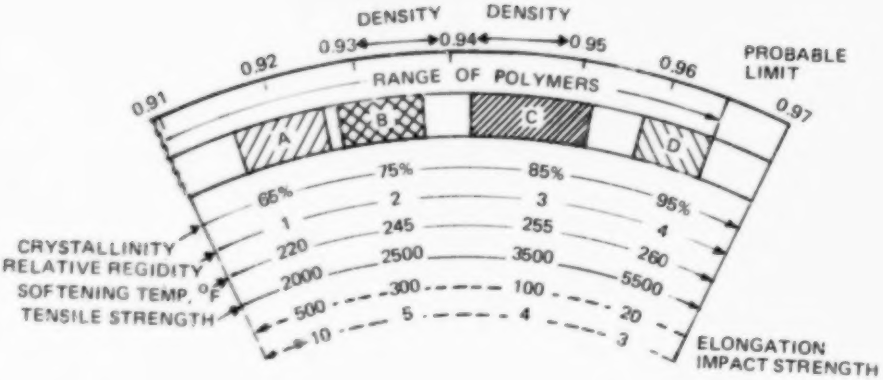

DENSITY
DENSITY
0.93
0.94
0.95
0.92
0.96
PROBABLE
LIMIT
0.91
RANGE OF POLYMERS
0.97
A
B
C
D
75%
85%
65%
2
3
95%
1
245
255
4
220
2500
3500
260
2000
300
100
5500
500
5
4
20
10
3
CRYSTALLINITY
RELATIVE REGIDITY
SOFTENING TEMP, °F
TENSILE STRENGTH
ELONGATION
IMPACT STRENGTH

Figure 6. Properties of polyethylene. Polyethylenes range in density from 0.91 to 0.97.

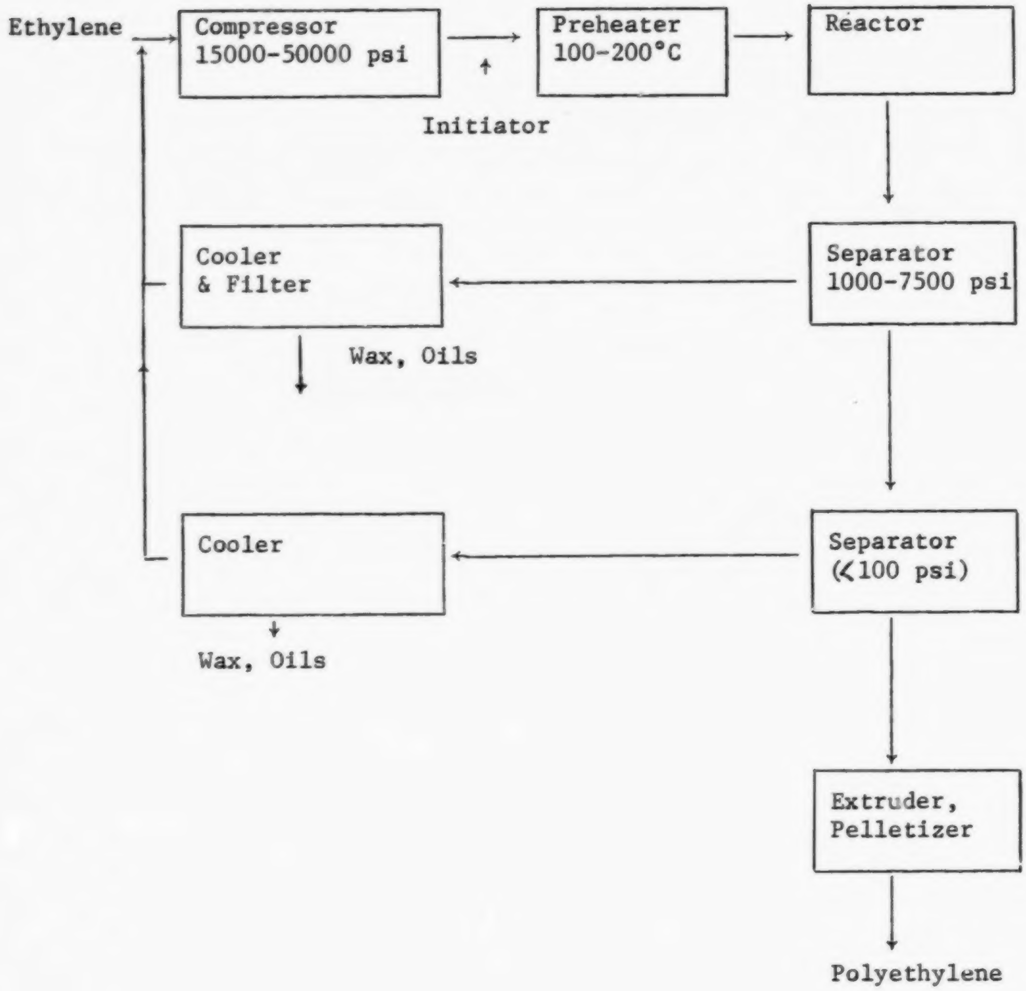

Ethylene
Compressor 15000-50000 psi
Preheater 100-200°C
Reactor
Initiator
Cooler & Filter
Separator 1000-7500 psi
Wax, Oils
Cooler
Separator (<100 psi)
Wax, Oils
Extruder, Pelletizer
Polyethylene

Figure 7. The high-pressure process for low-density polyethylene. This has an average overall yield of approximately 98 percent. More than one pass is required.

The densities of commercial polyethylene made by the high pressure process vary from about 0.915 to 0.935 g per cc; and the melt index can be varied from about 0.2 to 50.

High Density Polyethylene. All high density polyethylene is manufactured by low pressure processes. The major processes are the Phillips, Ziegler, and Standard Oil of Indiana processes. Today the Phillips process dominates and is estimates to account for approximately 60 percent or more of the high density polyethylene produced in the United States. While there are a great many differences in detail between the low pressure processes, all have strong basic similarities (Figure 8).

The low pressure processes use catalysts such as silica or silica alumina impregnated with a small amount of metal oxide. In the Phillips process the metal oxide is chromium oxide, and in the Standard Oil of Indiana process it is molybdenum oxide. In both processes, other metals or non-metals may be used to promote or modify the action of the catalyst. In the Ziegler process the catalyst is a complex formed by the reaction of an aluminum alkyl with a transition metal halide such as titanium tetrachloride. The catalyst preparation and activation techniques are very important, and determine not only the activity or efficiency of the catalyst but the properties of the polymer produced. These catalysts can produce as much as 6,000 pounds of polymer per pound of catalyst on a regular production basis. In these low pressure processes it is usually possible to obtain substantially complete conversion of olefin to polymer at one pass, obviating the recycling required in the high pressure process. Yields of 98 percent are easily obtained.

When separating the gas from the liquid at the conclusion of the reaction, some low molecular weight polyethylenes are entrained. These waxes and oils usually amount to no more than 0.1 percent. With the catalyst suspended in a hydrocarbon liquid, the reaction may be performed either as a solution or suspension polymerization, depending on the reaction temperature. Above 130 C the hydrocarbon is a solvent for the polymer, and below this temperature the polymer is insoluble and forms a suspension. In recent years the Phillips process has been modified to operate as a fluidized bed, gas phase reaction system without solvent. The Ziegler process can be conducted similarly.

Depending on the level of catalyst used, a catalyst removal step is often included. In the Ziegler system the simplest procedure is to wash the catalyst containing polymer with water or alcohol; and in the solution form of the Phillips system the catalyst residue is removed by filtering or centrifuging the reaction mixture. Normally superactive catalysts are used in the case of the particle form polymer (polymer produced in processes other than solution) so that the catalyst removal step is eliminated. Catalyst residues usually amount to no more than 10 ppm.

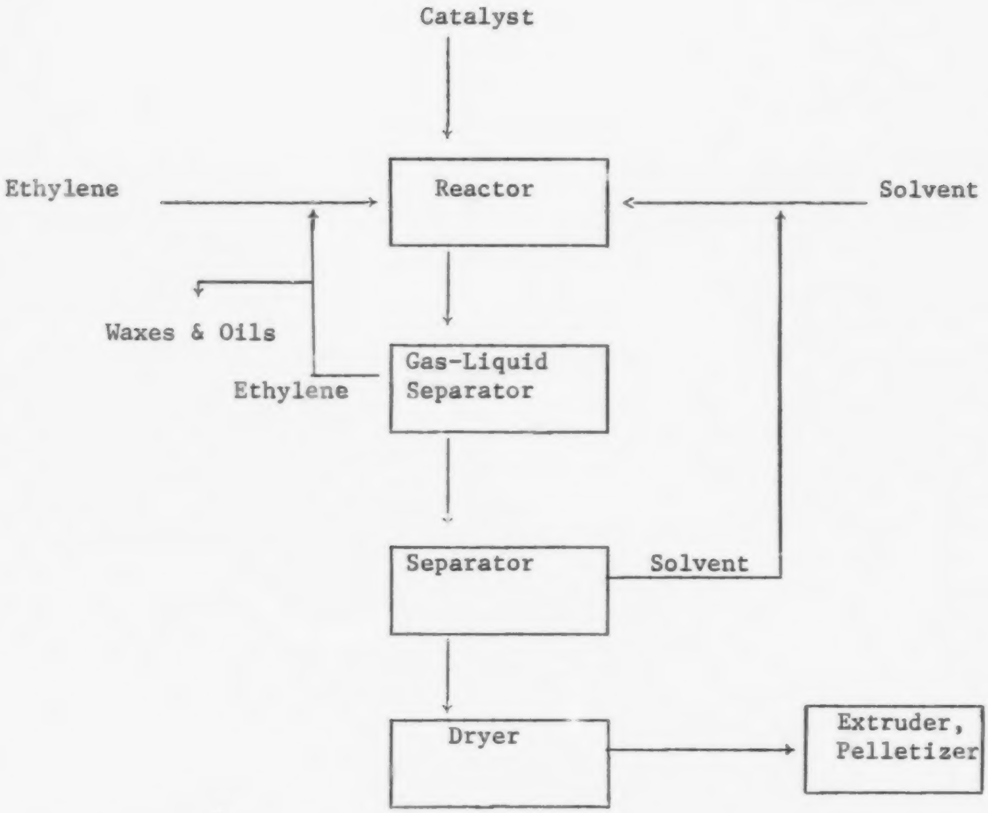

Catalyst
Ethylene
Reactor
Solvent
Waxes & Oils
Ethylene
Gas-Liquid Separator
Separator
Solvent
Dryer
Extruder, Pelletizer

Figure 8. The low pressure processes for manufacturing high density polyethylene uses organometallic catalysts.

Thus, particle form polymerization avoids costly catalyst removal and solvent recovery.

The polymer recovered either by precipitation or drying the slurry consists of very fine particles. Usually this form is not convenient to use in conventional plastics processing equipment; therefore, the normal finishing operation includes pelletizing.

The polyethylene from the Phillips process typically has a density of 0.960 to 0.970 g per cc, and the commercial Ziegler polyethylenes have a density range between 0.940 and 0.965. Phillips also has a process for making a low density polyethylene (0.939) by a low pressure system, which is a particle form rather than a solution process.

Structure and Properties. Many of the properties of polyethylene depend largely on its crystalline content, which in turn depends on the number of branches along the polymer chain. As more branches are introduced, crystallinity decreases rapidly. As discussed in an earlier section, high pressure polyethylene, which is about 50 percent crystalline, has about two branches per hundred carbon atoms; these are primarily ethyl and butyl groups. In contrast, low pressure polyethylene contains practically no branches, and crystallinity varies from 60 to 90 percent. The density of polyethylene correlates with its crystallinity. Thus, low pressure polyethylene yields a more tightly packed structure and a high degree of crystallinity.

The amount and type of branching can be controlled to adjust the crystallinity and, therefore, the density of polyethylene. In LDPE this is normally accomplished by control of the reactor conditions; in HDPE, branching is incorporated into the structure by adding varying amounts of comonomers such as butene or hexene during the polymerization. Furthermore, crystallinity and other properties also can be tailored by mixing the different polyethylenes as a blend to produce intermediate density materials. The crystallinity of LDPE also can be adjusted by using comonomers such as ethyl acrylate and vinyl acetate. These copolymers exhibit low crystallinity and, therefore, better flexibility and improved impact strength. The equilibrium melting point of linear polyethylene or HDPE is nearly 137 C. Normally, these polyethylenes have a melting range of 132 to 135 C. The low density polyethylenes melt at about 112 C, and have a broad melting range.

Probably one of the most important properties of polyethylene is its elastic modulus or stiffness. This, together with tensile strength increases linearly with density.

Polyethylene has excellent chemical resistance. It is resistant to water and aqueous solutions; even fuming sulfuric and nitric acids attack the polymer only slowly. In general, below 60 C, polyethylene is resistant to most common solvents.

One of the peculiarities of polyethylenes is that they are subject to ‘‘environmental stress cracking.’’ This effect is characterized by the formation of brittle appearing fractures under very low tensile stress conditions, and usually occurs in the presence of agents such as alcohols or an aqueous solution of soap or a wetting agent. Eventually the polyethylene article fails under moderate stress, though no evidence of etching, swelling, or chemical attack appears.

Environmental stress crack resistance generally improves as the melt index and/or the density of the polymer decreases. In general, polyethylenes containing only low concentrations of low molecular weight species exhibit improved resistance to environmental stress cracking. High density polyethylene containers for detergents and shampoos use a grade with a density of 0.95 g per cc. Where stress crack resistance is not significant, as in milk containers, polyethylene with a density of 0.96 g per cc is used.

Because polyethylene is used in film form, its behavior towards various vapors and gases is very important. While polyethylene has a low water permeability, it is rather permeable to organic vapors as well as oxygen and nitrogen. High density polyethylene is slightly less permeable to these gases than is the low density variety, but most film is made of the latter polymer.

Like most polymers, the properties of polyethylene can be adjusted by the use of additives and fillers. Antioxidants are added to prevent serious losses in properties during processing and use, and they are normally incorporated by the resin producer during the finishing operation. Most polyethylene is solid with an antioxidant. For film applications, slip and anti-block agents are required. Blocking is the tendency of film to stick to itself, and it is reduced by adding finely divided inorganic fillers such as silica. To improve weathering resistance, carbon black is often added in concentrations up to 30 percent. This particular compound is sold to the wire and cable industry and to many segments of the plastic pipe industry.

Applications. LDPE is used when flexibility, clarity and toughness are desired, and HDPE finds utility where hardness, rigidity, and higher strength are important. Within each type of polyethylene a broad selection of grades is available. These have a wide range of densities and melt indexes. For example, LDPE film compounds usually have a melt index between 1 and 5 and a density between 0.920 and 0.925 g per cc, and LDPE used to coat paper board (e.g., milk carton stock) has a melt index of 3 to 12.

Most polyethylene containers are made from HDPE. These compounds generally have a low melt index (less than 1.5). On the other hand, for the manufacture of molded goods, high flow is needed. Here a very broad range of melt index is used: from 3.5 to 20.

All wire coating applications have very stringent needs. LDPE and HDPE insulating compounds have flow properties that are specially tailored for smooth, high speed flow, and for cable jackets, outstanding physical and stress crack resistance properties are required. Table 9 lists the major application areas for polyethylene. As one goes down the list, the specifications become less critical and resin price goes down. Thus, the more rigidly specified compounds are those used for wire and cable, and the broader specified compounds are used for molded goods and utility pipe.

Polypropylene

While smaller in production volume than polyethylene, polypropylene sales have been growing rapidly for the past few years. Polypropylene has a wide range of desirable properties. This polymer has excellent processability; it can be used to mold very thin wall parts. But most significantly, polypropylene, in contrast to polyethylene, can withstand heat sterilization temperatures without deformation.

Raw Materials. The monomer, propylene, which is chemically similar to ethylene, is a normal by-product of catalytic or thermal cracking of gas oil and the production of gasoline. In the U.S., much of the propylene and ethylene is derived from natural gas liquids and some liquified petroleum gas. Where propylene is in short supply, it is produced by thermal cracking of naphtha. Both ethylene and propylene can be made this way.

Propylene recovered from the normal cracking operations in refining is generally low in acetylenes. On the other hand, high temperature cracking of naphtha generally leads to higher yields of acetylenes (up to 100 ppm), and these components are then removed by absorbents or by selected hydrogenation. Polymerization grade propylene must be essentially free of these impurities.

Manufacturing Processes. A Ziegler type catalyst system is used to polymerize propylene similar to that used for linear polyethylene. To obtain high yields of ''isotactic'' polypropylene (that portion of the polymer that is crystallizable) catalysts based on titanium trichloride are used. Typically, overall yields are about 97 percent.

Propylene polymerization is generally conducted at 25 to 100 C in an inert hydrocarbon medium. The polymer precipitates as it forms, and the final product is recovered as a granular powder.

This process is similar to that used to manufacture HDPE. A small amount (1.5 to 3 percent) of ''atactic'' polypropylene forms during the

TABLE 9

POLYETHYLENE-SPECIFICATION REQUIREMENTS

LDPE	Performance requirements and relative price of resin	HDPE
1. Wire & Cable	High	1. Wire & Cable
2. Clear Film		2. 1st Line Pipe
3. Rigid Containers		3. Sheet & Film
4. General Purpose Film		4. Rigid Containers
5. Utility Pipe		5. Molded Goods
6. Molded Goods	↓ Low	6. Utility Pipe

polymerization. This fraction is essentially amorphous and remains dissolved in the hydrocarbon layer. Thus, when the solvent is distilled, and the isotactic polymer separated, the atactic polymer is recovered as a distillation residue. Most manufacturers burn this material; however, one of the manufacturers that we interviewed sells the atactic fraction as a varnish or adhesive component.

In the finishing operation, the catalyst is deactivated by mixing the reaction mixture with alcohol or water, and the powdered polymer is recovered by filtration or centrifugation. In some processes the polymer is recovered as a flake. Almost all polypropylene is mixed with an antioxidant, and the compound is either extruded and sold as pellets or as a dry powder blend.

Structure and Properties. Polypropylene has the lowest density of commercially available thermoplastics (0.905 g per cc). It exhibits high rigidity, exceptional flex life, and good surface hardness. It is essentially unaffected by most chemicals and is not subject to environmental stress cracking. The outstanding feature of polypropylene is its high temperature properties. With a crystalline melting point of 335 F, polypropylene retains structural integrity in boiling water and can be sterilized at 250 F. It can be used in applications requiring continuous exposure to temperatures as high as 225 F. If desired, the impact strength and low temperature properties of polypropylene can be improved by copolymerizing it with ethylene or by compounding it with certain elastomers.

Typically, polypropylene contains 50 to 60 percent crystalline isotactic, 20 to 30 percent amorphous isotactic, and 10 to 20 percent amorphous atactic polymer. The amounts of amorphous isotactic polymer can be varied depending upon the extent of annealing of the sample. Thus, much of the polymer can be considered crystallizable.

Applications. Polypropylene is widely used by the automotive industry, which takes advantage of the plastic's high stiffness and scuff resistance, and its good processing characteristics. Many molded articles are used for hospital ware, because polypropylene items are sterilizable, and food grade polypropylene is available for packaging applications. Its outstanding clarity, high gloss, and sparkle make it an excellent packaging film. Furthermore, orientation of polypropylene film improves its low temperature properties, and greatly decreases the permeability of the film to different gases. This is often an advantage.

Polyvinylchloride

Polyvinylchloride (PVC) or vinyl is used in an extremely broad spectrum of applications. Not only are a wide variety of polymer types available, but they are easily modified with numerous additives such as stabilizers, plasticizers, fillers, impact modifiers, etc. End uses range from medical tubing to phonograph records to packing film and bottles to house siding and down spouts. Furthermore, this material has excellent cost/performance characteristics, inherent chemical resistance, and is virtually self-extinguishing.

Raw Materials. Vinyl chloride is a colorless gas, but industrially it is handled as a liquid because its boiling point is -13.9 C. Currently this monomer is produced commercially by two different methods. The older reaction merely involves the addition of hydrochloric acid to acetylene using a mercury catalyst. The reaction is initiated at about 80 C, and most of the reaction takes place at about 150 C. The final operating temperature may be as high as 250 C.

The second method for preparation of the monomer involves oxy-chlorination of ethylene to form ethylene dichloride, which is subsequently cracked to vinyl chloride. The economics of this method are very favorable, and the majority of vinyl chloride produced today uses this process. Typically, in the oxy-chlorination step a catalyst of copper and alumina is used, and the reaction is conducted at temperatures from 200 to 350 C.

Recently, Lummus announced a new process.[1] Their proprietary process produces vinyl chloride directly from ethane with no by-products for at least one cent lower materials cost per pound of product. The starting materials are ethane, chlorine, and air.

Manufacturing Processes. Vinyl chloride is polymerized by a free radical initiator such as an organic peroxide, rather than an organometallic catalyst. There are essentially three commercial polymerization processes for manufacturing PVC: suspension, emulsion, and bulk polymerization. Suspension polymerization is most commonly used today. It accounts for over 80 percent of the production. In this process, vinyl chloride is suspended in water aided by a small amount of a suspending agent (Figure 9). The reaction temperature is generally between 45 and 55 C, under moderate pressure. Typically, yields of approximately 95 percent are obtained. The molecular weight of the polymer is generally controlled by the reaction temperature and/or the addition of modifiers. At the completion of the reaction, unreacted monomer is recovered in the stripper; the solid polymer, which is usually in the form of fine beads, is recovered by centrifugation. Depending upon the ultimate application, the product may be sold as: (1) an unstabilized polymer, usually in powder form as it is obtained from the reactor; (2) as a dry powder blend with additives and/or colorants; (3) as a pelletized compound prepared using an extruder or a 2-roll mill and a dicer (see section ''Compounding'').

The so-called ''paste resins'' are made by emulsion polymerization. As the name implies, the monomer is emulsified in water using a surface

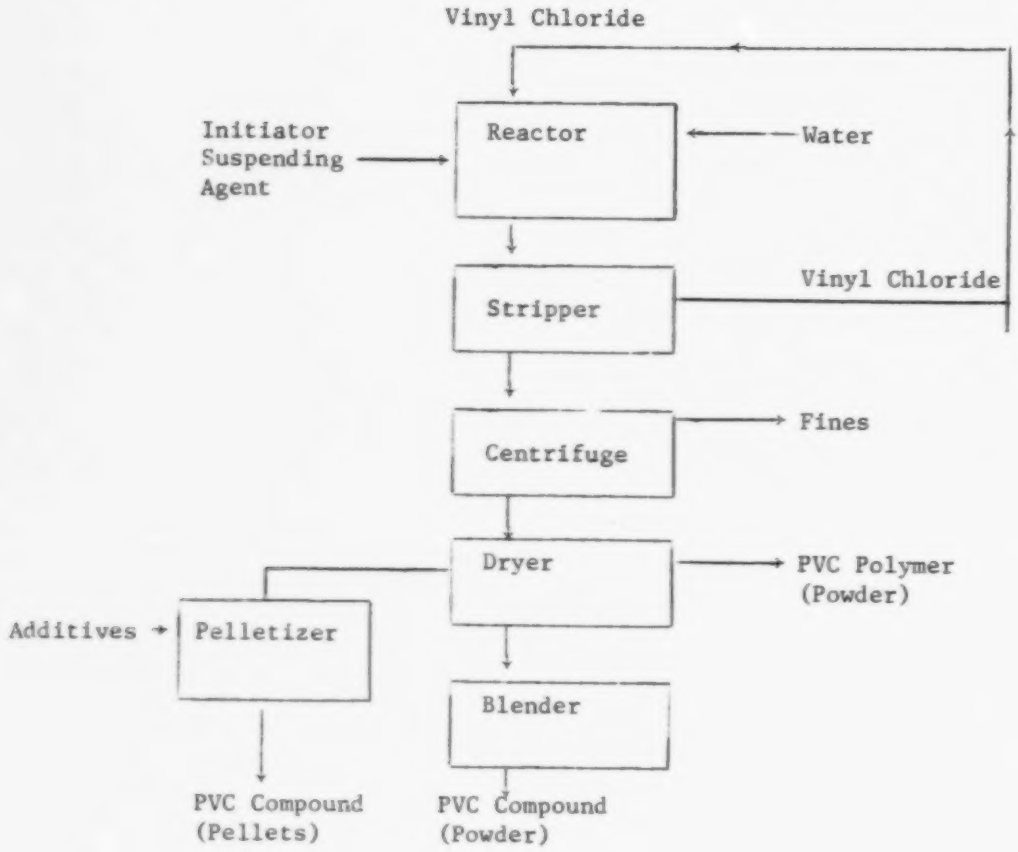

Vinyl Chloride
Initiator
Suspending
Agent
Reactor
Water
Stripper
Vinyl Chloride
Centrifuge
Fines
Dryer
PVC Polymer
(Powder)
Additives
Pelletizer
Blender
PVC Compound
(Pellets)
PVC Compound
(Powder)

Figure 9. Polymerization of vinyl chloride--suspension system. The reaction temperature is generally between 45° and 55°C, and the pressure is moderate.

active agent. The difference between suspension and emulsion systems is primarily a difference in the size of the suspended monomer droplets; they are much smaller in the emulsion system. The polymer from the emulsion process is recovered either by coagulation or spray-drying. The latter technique is preferred for plastisol type products (Plastisols are discussed below). One of the disadvantages of the emulsion polymer is that is usually contains residual surface-active material, which has an adverse effect on properties such as clarity.

Bulk polymerization is the latest method to achieve commercialization. Here the monomer is polymerized in the absence of solvent. The reactors are especially designed to handle bulk polyvinylchloride at elevated temperatures. These bulk polymers apparently have several desirable features. For example, the recovered particles have high porosity and clarity and relatively uniform shape and size.

Structure and Properties. Polyvinylchloride is primarily an amorphous polymer, although conventional products can have crystallinity up to 5 percent. PVC made at lower temperatures can have as much as 25 to 30 percent. The polymerization temperature affects both the glass transition and melting point temperatures of PVC. For example, a reaction temperature of 40 C yields PVC with a glass transition temperature of 80 and a melting point of 220 C. At -15 C, the glass transition temperature of the product is increased to 105 C and the melting point to 285 C. However, most pure commercial PVC polymers have a glass transition temperature of about 80 C.

The mechanical properties of PVC depend on the formulation of the compound. If it contains only about 3 percent of stabilizers and lubricants, it is called rigid PVC, and if it contains plasticizers, it is called flexible PVC. The latter has a soft rubbery appearance at room temperature because the plasticizers reduce the melt viscosity and lower the glass transition temperature or the stiffness of the compound.

Rigid PVC. These compounds can be formulated to offer materials ranging from glass clear to opaque, with outdoor durability, or for food packaging. They have good chemical resistance to most acids, alkalies, moisture, oils, and greases; and polymeric modifiers can be used to improve their impact strength and processability. Rigid vinyl is used today in applications such as pipe, various molded goods, blister packs, and bottles. It is especially appealing for bottles, not only because of its clarity and rigidity but also because it widens the choice of products that can be contained in plastic bottles. PVC has a low oxygen permeability; therefore, food products that must be held in a low oxygen atmosphere, such as shampoos, flavoring ingredients, etc., can be packaged in bottles using this material.

Flexible PVC. Generally, the highest molecular weight polymer goes into the flexible compounds, whereas the lower molecular weight material is used for many of the rigid items cited above. Solvent absorption characteristics of the polymer used for the flexible grade are important, therefore, specially prepared, highly porous polymer is used. These polymers usually can absorb plasticizer in amounts equal to their own weight. The type of plasticizer used can significantly affect properties, as discussed in the section on plasticizers. Plasticizers are therefore selected according to the compound's end use.

One of the major applications for flexible PVC is film. They can be made very soft and tacky, or hard and slippery, depending on the application. PVC film can be used in both manual and machine wrapping; it is easily heat sealed. Thus, unsophisticated equipment can be used, which makes it easy to use in supermarket wrapping. One of the largest uses for this film is for in-store packaging of fresh meats. PVC is preferred because of its low oxygen permeability, therefore, the film maintains the color of the fresh meat. Moreover, it has good ''eye appeal,'' because it has excellent clarity. PVC film is also used for produce wrapping.

Because of its excellent weather resistance, flexible PVC is also used in items such as weather stripping, swimming pool liners, and wire and cable. PVC is easily colored and can be produced with good wear resistance; therefore, a major application for flexible PVC is for upholstery and wall covering. Other applications include outerwear and apparel, auto mats, toys, and inflatables. Bottles and film require specified PVC compounds, according to the criticality whereas products such as flooring and molding can use a range of compounds (Table 10).

Plastisols. Polymer made by the emulsion process, the so-called dispersion resins, is used to produce liquid plastic dispersions commonly referred to as ''plastisols.'' These are used for coating a variety of substrates or for molding into flexible articles. The polymer for this application is high in molecular weight, and the size of the polymer particles is extremely small (ranging from 0.1 to 2 microns).

The plastisols when formulated with plasticizer and various other ingredients result in a product that can range in viscosity from a light oil to a thick putty and can be designed to display a variety of physical properties to suit a multiplicity of end uses. When heated, the plastisol is converted to a product that can be soft or hard and have good resistance to heat, cold, and chemicals. It also can offer excellent resistance to impact, tear, or abrasion; it can be virtually odorless, tasteless, non-toxic, and colored. Plastisols are used for various coating applications and, in particular, for coating fabrics. They are also used for toys and articles such as rubber boots.

TABLE 10

POLYVINYLCHLORIDE-SPECIFICATION REQUIREMENTS

Rigid	Performance requirements and relative price of resin	Flexible
1. Bottles	High	1. Film
2. Sheet (clear)		2. Tubes (packaging)
3. Pipe		3. Sheet
4. Moldings & Profiles		4. Coated Fabrics
		5. Wire & Cable
		6. Moldings & Profiles
	↓ Low	7. Flooring

Styrene Polymers

The range of products made from styrene polymers also is extremely broad. Special properties to meet specific applications are readily obtained by the use of additives and/or copolymerizing styrene with other monomers. All products in this family are lightweight, rigid, easily processed, and readily colored. Physical properties of the compound, such as tensile and impact strength, elongation, stiffness and heat distortion can be readily varied.

Raw Materials. Styrene is a liquid (BP 145 C) which can be handled easily and safely. It is manufactured by the dehydrogenation of ethyl benzene, which is obtained by the reaction of ethylene with benzene. Super-heated steam is mixed with the ethyle benzene prior to its contact with the dehydrogenation catalyst, which is primarily an iron oxide. Recently, Monsanto developed an improved process for this step that uses steam even more effectively than the existing processes.

Manufacturing Processes. Styrene polymers can be produced by three distinct types of processes that vary according to the solvent medium. The processes are: mass polymerization without diluent; suspension polymerization; emulsion polymerization. These processes resembly those for the polymerization of vinyl chloride in aqueous systems, but in the finishing step most polystyrene is pelletized.

The so-called general purpose styrene (‘‘crystal’’ polystyrene) is manufactured primarily by the suspension polymerization process. Some manufacturers use a variation that includes bulk polymerization. Adding comonomers such as acrylonitrile and methylmethacrylate is also possible using these processes. Peroxide initiators catalyze the polymerization reaction, and typically a combination of initiators is used to obtain a rapid reaction and produce a polystyrene with little residual monomer. Water insoluble inorganic compounds are often used as suspending agents. When the polymerization is completed, the polymer is washed with water, separated by centrifugation, dried, and pelletized.

To make the ‘‘expandable beads’’ for foamed polystyrene products, a propellant or blowing agent is added to the suspension system. Typically a volatile hydrocarbon is used that becomes entrapped in the beads that form during polymerization.

Rubber modified polystyrene, known as impact polystyrene, consists of discrete particles of rubber dispersed in a polystyrene matrix. In most instances, this product is made by first dissolving the rubber (3 to 10 weight percent) in styrene and carrying out a bulk polymerization without catalyst to a low conversion (10 to 20 percent). At this point, the rubber phase forms small particles in the dispersed plastic phase.

This mixture is then suspended in water together with an organic suspending agent, peroxide initiators are added, and the reaction is completed as a suspension polymerization. The finishing operation is similar to that for general purpose polystyrene.

If, instead of styrene, a solution of styrene and acrylonitrile is used with the rubber, ABS (acrylonitrile-butadiene-styrene) polymers are produced. Most commonly the rubber is introduced as a latex and, therefore, ABS is made by emulsion rather than suspension polymerization.

These rubber based systems are almost infinitely variable. Adjustment of the rubber concentration, composition, and structure within the plastic matrix leads to impact resins that are classified as low, medium, or high. The molecular weight and molecular weight distribution of the plastic phase are also important variables and are controlled to give specific properties.

General Purpose Styrene Polymers. Polystyrene of high molecular weight (greater than 80,000) and with a low volatile content has a glass transition temperature of approximately 100 C. The commercial polystyrenes with an approximate average molecular weight of 220,000 are amorphous with essentially no crystallinity. They are clear and colorless and have good physical and dielectric properties, dimensional stability, and low specific gravity. Depending on their formulation, heat deformation temperatures range from 150 to 210 F. Although polystyrene has good resistance to water and indoor environments, it is not normally recommended for extensive outdoor exposure. It is resistant to many mineral oils, salts, and lower alcohols. However, it is softened or dissolved by many hydrocarbons, ketones, and essential oils. Polystyrene should not have more than 0.5 percent residual styrene, if it is used for packaging foods.

With appropriate control of polymerization condition and the use of additives, polystyrenes with varied fabrication and use characteristics can be made. Improved flow is usually achieved at the cost of lowering the heat deformation temperature. Typical additives used with polystyrene resins are: lubricants, anti-static compounds, mold release agents, and compounds to maintain light and heat stability.

Styrene-acrylonitrile copolymers (SAN) are also available. These usually have about 24 percent by weight of acrylonitrile. SAN is transparent and, in comparison to polystyrene homopolymer, it is tough and more solvent resistant. Because of its clarity and rigidity, SAN is commonly used for housewares. toys, novelties, packages, and appliances.

Foamed Polystyrene. Rigid plastic foams manufactured from polystyrene are more widely used today than any other rigid plastic foam material. There are two distinct types of polystyrene foam: (1) moldable foam made by expanding polystyrene beads containing a blowing agent; (2) extruded polystyrene foam which is produced by expanding a hot mixture of general purpose polystyrene, blowing agents, and additives through a slit orifice to about 40 times its pre-extrusion volume (see section ''Processing''). This type of foam is used in the form of boards and billets, and the molded polystyrene foam is used to make large blocks and and items such as drinking cups.

Polystyrene foam offers very low thermal conductivity, good resistance to water vapor transmission and high static forces without deformation. These special properties have made polystyrene foam particularly useful as insulation board and for low temperature applications in cold storage areas, refrigerated display cases and piping. It is also used for roof insulation, because it has both low thermal conductivity and good structural strength. In masonry construction, the extruded polystyrene foams are also used as a combination insulation and plaster base. Polystyrene foam is very very useful in packaging as molded foam packaging components and foamed cups. The foamed cups are rapidly displacing paper cups today because they are lightweight and have superior insulating properties.

Rubber Based Styrene Polymers. General purpose polystyrene is very brittle. Where greater elongation and impact resistance are needed, rubber based impact polystyrene is used. Generally these have flow strength and heat resistance ranges similar to those of the general purpose material. Because rubber based polystyrenes have two phases, they are not transparent. Grades of impact polystyrenes are available that differ in impact strength, heat deflection temperature, melt flow, tensile, elongation, etc.

The related ABS polymers possess an excellent combination of mechanical and physical properties; they are generally considered engineering plastics with a high strength to weight ratio. They are rigid and have excellent impact strength (considerably higher than impact polystyrene) both at room temperature and at low temperatures. ABS polymers are also more solvent resistant than impact polystyrene. These polymers process easily, and have a minimum tendency to orient during molding. Most grades of ABS have a heat distortion temperature of about 200 F.

Impact polystyrene goes where toughness is required--automotive applications, sporting goods, luggage, shoe heels, etc. The heat resistant grades are used in TV sets and radios where both toughness and good chemical resistance are required. ABS has found its way into products such as instrument panels, arm rests, business machines, telephones, and various appliances.

PROCESSING

Up until now, we have always alluded to the term processing without fully describing it. Broadly speaking, processing is transforming a polymer or compound to a useful plastic item. Processing as cited in this report can be divided into three types of activities: (1) compounding--the process of mixing the polymer with additives or colorants; (2) fabricating--the process of transforming the resulting compound or uncompounded polymer to a finished or semi-finished plastic or plastic containing end item such as film and bottle, or tubes and sheets; (3) converting--the process of modifying a fabricated plastic product by decorating it, cutting, or sealing it. Each of these activities is described below in detail.

Another activity that is included under processing is reprocessing, which is the operation required to recycle plastics. Reprocessing is the process of converting scrap plastic to a useful material. Normally, this requires remelting the scrap to reshape it. Scrap is often generated during the manufacture of plastic items--industrial scrap. It may be in the form of contaminated compound, film trimmings, strands, or large chunks of plastic from the molding machinery. If the scrap plastic (SP) is not reprocessed nor reprocessable, it becomes nuisance plastic (NP).

The product obtained by reprocessing scrap plastic is called secondary resin. This material competes with virgin prime resin and, particularly virgin off-grade resin. (See Part II ''Economics of the Plastics Industry.'') Prime resin is a resin that only has been subjected to the minimum number of heat histories required in its production, and it meets the required specifications. Off-grade resin is similar to prime, except that as prepared it did not meet the original customer's specifications. Generally off-grade has a wide specification range and is used to fabricate plastic products that do not require raw material with tightly controlled specifications. Resin produced as the manufacturer changes his manufacturing line from one grade to another, the so-called ''transition material,'' and that produced in experimental runs, also become off-grade resin.

To recycle or reprocess plastics, they must be homogeneously one plastic type and free of foreign matter. In our report, these are called monoplastic products. If the plastic item contains more than one plastic compound, as in a laminate, it is a multiplastic, and if the end item contains both plastic and non-plastic materials, it is considered a composite.

Compounding

In the narrow sense, compounding is mixing; it signifies the dry mixing or blending of powders, but more broadly, it signifies mixing in a melt to produce pelletized or diced resin. Dry blending is mostly used to prepare PVC powders, but other compounds are prepared similarly. Because of the heat sensitivity of PVC, many fabricators prefer to use it in powder form instead of pellets to minimize degradation during fabrication. Dry blend compounds are more economical, particularly if compounding is done by the fabricator.

Dry blending requires that the ingredients are: (1) free flowing, (2) high in bulk density (i.e., not too fluffy), (3) free of volatile constituents, (4) free from a tendency to separate into their original state, (5) free from a tendency to cake or agglomerate. An important factor is particle size. Typical PVC resins for dry blending have a particle size ranging from 3 to 6 mils. A narrow particle size distribution is preferrred.

Dry blending, e.g., in dry coloring, is frequently accomplished in mixing equipment such as a ribbon blender or a vertical auger mixer. For more difficult blending, as in the mixing of impact modifiers with resin, a high shear mixer is required. The most widely used units resemble a high speed household mixer with a vertical beater shaft driven from underneath. The intensive stirring usually heats the material being mixed.

Pellet compounding is usually accomplished by extruding (see section ‘‘Fabrication’’) multistrands or tapes of plastic that, after cooling, are cut to produce pellets. Another method involves melt blending in a Banbury mixer and then feeding the melt to a two-roll mill to produce a plastic sheet. The sheet is then dice cut into pellets. In both systems, mixing is usually accomplished during the melt processing, although for extremely difficut mixing problems, dry blending may precede melt blending.

The Banbury mixer (reg. Trademark, Farrel Corp.) is a very effective mixing device. It has a mixing chamber equipped with special rotor blades that are somewhat elliptical in cross section, and the clearance between the blade and chamber is small. Polymer and additives are charged to the mixing chamber and melted by the vigorous mixing action of the blades; if required, the chamber can be heated. In many cases, the pellet phase is omitted, and the sheet stock from the mixer is used to fabricate an end item directly. If extrusion is used in the compounding process, then normally a number of special screw designs are employed to combine adequate mixing with melting.

Often a particular compounding unit is selected for a product area. The more viscous the molten mixture, the more intense the compounding process must be. This is noticeably true when particulate and especially fibrous fillers are added to polymers. Adequate mixing is very important, because improper compounding can yield inferior products.

Scrap Plastic Generation. In the Banbury compounding operation drippings from the Banbury mixer and the mill, as well as stock from aborted runs are potential sources of NP. In dry blending, agglomerates of the powder can occur. These are removed by a screen and are usually discarded as NP.

Extrusion compounding leads to scrap plastic that is in the form of large chunks or strands. This scrap is generated by the purging operation which is required to clear the extruder, as one changes from one product line to another (''transition'' material). Faulty operation of the extruder (overheating, etc.) or the inadvertent contamination of the feed, all lead to the generation of scrap or nuisance plastic.

Whenever possible, the scrap is reused in the compounding equipment, or it is sold to a reprocessor. NP generation varies with the type of operation. A company involved in custom compounding producing a wide range of products, particularly colored ones, can generate 1 to 2 percent NP, whereas a resin producer who does compounding in line with his polymerization equipment will generate as little as 0.2 percent NP.

Fabricating

In this process the raw materials are usually used in powder or pellet form, but in some instances the formulas are liquids. Occasionally compounding is done in-line with the fabricating process, and in other cases fabricating is combined with the converting process (printing, cutting, etc.). Some time all three operations occur in a single piece of equipment.

Injection Molding. Of the many fabricating processes for plastic compounds, the best known and most widely used is probably injection molding. It is used primarily for thermoplastic compounds, and polyolefins and polystyrene in particular. The current trend, however, is toward injection molding of thermosetting compounds and thermoplastics containing fillers.

Process. Injection molding is basically a process of heating a plastic material into a melt in a heating chamber and forcing this melt through a nozzle under high pressure into a closed mold which abuts firmly against the nozzle. The melt feeds into the mold cavity through small diameter runners and gates, and in the mold the melt is cooled and solidified into the shape of the cavity.

Originally injection machines consisted for a simple heating cylinder with a plunger for moving the molten mass. However, in recent years, the ram or plunger of the injection machine has been replaced by a screw, which is more efficient in plasticating the resinous materials. The reciprocating motion of the screw duplicates the function of the plunger (Figure 10). A few designs include combinations of these two principles--the most popular are the screw plunger and the plunger-plunger types of machines. However, over 75 percent of all machines currently sold are basic single stage reciprocating screw machines, and the percentage is increasing.

While manufacturers still sell single stage plunger machines, these are used infrequently, because they do not provide good mixing. Improper mixing leads to problems of temperature control, poor pigment dispersion, and degradation of the resin. However, plunger machines (or some variation thereof) could perhaps be attractive for molding products with recycled plastics to yield mottled or marbleized color patterns. Here poor mixing is an asset.

The injection molding process is very versatile, and the technology is well developed. It produces three dimensional parts to close tolerances. But most significantly, the process is capable of extremely high outputs per hour and is usually most economical when production volume is high. Molding machines will accept virtually all injection molds--within the proper range of sizes, of course.

Cooling is a critical part of an injection molding cycle. It normally accounts for 75 percent or more of the total cycle time. Simple products, such as thin wall, throw away drinking cups are molded in cycle times of about 1 to 1-1/2 seconds with 1/2 to 3/4 seconds for cooling. Most parts required by industry are thicker and thus require considerably longer cycle time--from 10 to 20 seconds.

Injection molding of thermosetting materials is more difficult than molding of thermoplastics. Under heat, thermosetting plastics, as mentioned earlier, first soften and then harden to an infusible state. Thus, it is essential that no softened thermosetting material be allowed to remain in the heating chamber long enough to set. Reciprocating screw type machines overcome this problem by liquefying the thermosetting plastic material just as it goes through the injection nozzle into the mold, but not before.

Thermoset injection molding in the United States is used primarily for small parts, while molding machines for thermoplastics are constantly getting larger. The largest tonnage thermoplastic press delivered to date is a 5,000 ton unit.

The major disadvantage of injection molding is that it has a relatively high mold cost and, therefore, requires large production volume to warrant this type of expenditure. Another disadvantage is that undercuts are difficult or impossible to mold without having complex moving parts in the mold. Because all molten material must pass through the wall areas

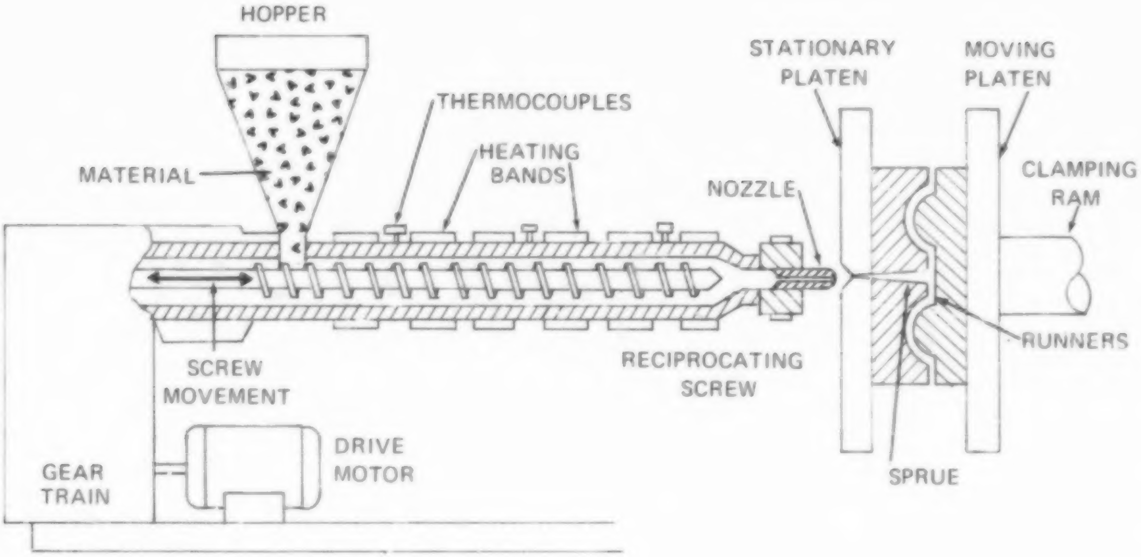

HOPPER
STATIONARY PLATEN
MOVING PLATEN
THERMOCOUPLES
HEATING BANDS
MATERIAL
NOZZLE
CLAMPING RAM
RUNNERS
SCREW MOVEMENT
RECIPROCATING SCREW
DRIVE MOTOR
GEAR TRAIN
SPRUE

Figure 10. Reciprocating screw injection molding machine. In a reciprocating screw injection molding machine plastic material is melted by heat and friction between the rotating screw and the barrel.

formed by the mold, thin walled structures are also difficult to mold. However, other processes, like blow molding and thermoforming, discussed below, can produce products with much thinner wall construction.

Product Area. Injection molding is used for a wide range of end products utilizing a variety of resins, colors, shapes and special effects. Because it makes products to close tolerances in all three dimensions, it can produce highly engineered products. On the other hand, it also can produce low cost consumer disposable products. Wall thickness of parts is generally under 0.100 inches, although parts with thicknesses up to several inches are injection molded.

Typical injection molded thermoplastic products include: boxes, tubs, caps and closures, disposable cups, dishes and eating utensils, appliance housings, telephone sets, houseware items, refrigerator parts, automotive steering wheels, knobs, lenses, electrical components, sporting goods, toys and novelties.

Raw Material Requirements. Generally, the condition of raw materials used in the injection molding process has to be carefully controlled. Uniformity of granule size of the resin is important because non-uniformity leads to feed problems, pressure loss (in plunger type machines only) and temperature control problems. Air entrapment causes streaking and bubbles in the molded article. Furthermore, the ability of the injection molding process to tolerate long fibers or large filler particles is limited. Moisture can be a serious problem. Under the high temperature and pressure of the molding process, water vaporizes and causes bubbles.

Compounds having low melt viscosity (free flowing) are required in order to permit flow in the passages of the molds. These are produced by using low molecular weight resins plus lubricants and processing aides. Most injection molding compounds range in melt index from 5 to 50 (as contrasted to a range of 0.1 to 2.10 for blow molding). Melt index consistency is critical for injection molding. For example, a lot having a melt index of 4 should range only from 4.0 to 4.5.

The process currently has the capability of using certain mixtures of resins and some mixing is practiced. The polyolefins--LDPE, HDPE, ethylene vinylacetate, and polypropylene are currently mixed to some extent. However, injection molding also has a tendency to produce single direction orientation which can produce laminar structures in mixed compounds.

Scrap Plastic Generation. Sprues and runners from the molded articles and scrap from rejects are usually reground and reprocessed in amounts ranging from 1 to 15 percent, but in many cases as high as 50 percent is used. Some products have even been injection molded using 100 percent regrind; thus, a low percentage of nuisance plastics is generated. In most operations the average is less than 1 percent NP. These are in the form of dirty grindings and floor sweepings, large chunks (50 to 200 pounds) from purging, and contaminated moldings. If a variety of small runs are made with different colors, regrind is more difficult to use and NP generation can increase from 2 to 4 percent. Reject material from this operation varies from company to company. It can vary from 1 to 3 percent. Depending upon the particular operation, rejects can be recycled either in the fabricator's facilities or sent to a reprocessor. Only if the molded product is badly contaminated does it end up in the disposal area.

Ability to Tolerate Scrap Plastic. The tolerance of the injection molding process for scrap plastic as currently practiced is low. Large specks of unmelted or decomposed material can clog the injection nozzle, runners, gates, or narrow areas in the mold cavity. No filters are normally used in the process. However, screen packs (such as used in extrusion) could be designed into the process. Processing of contaminated scrap could be carried out with one or more automatic screen changers that could be built into an injection molding machine or into the systems for refining the scrap plastics. On the other hand, the high pressures, compacting action and the melt state of the resin during the process do offer the possibility of utilizing resin contaminated with particulates and foreign resin. Thus, with modifications, the injection molding process potentially offers a good method of converting scrap plastics into usable products.

Extrusion General. The basic machine of all extrusion processes is the extruder. An extruder consists of a metal barrel, a close fitting internal screw (or screws) connected to a drive mechanism, and a means for applying heat to the barrel in one or more zones. The process consists basically of mixing and melting a continuous stream of plastic and pushing it through a specially designed orifice or die by the turning action of the screw(s).

Extrusion is used for making continuous lengths of profiles. A profile varies only in two dimensions, as opposed to molded products which vary in three. Major profile product areas are: film and sheet, extrusion coating (wire, textiles, paper, etc.), pipe, rod and special profile tubing, and coextrusion.

Extruders are available with either single or multiple screws and can be vented for removal of volatiles. The single screw extruder is the most common because of its simplicity, low cost, versatility, and ruggedness (Figure 11). Multi-screw machines, especially the twin screw, are used primarily for compounding resins during the fluxing or melting portion of a fabrication process. Vented extruders are used to remove volatiles such as residual monomers, moisture, and trapped air, which might otherwise cause bubbles or other defects in finished

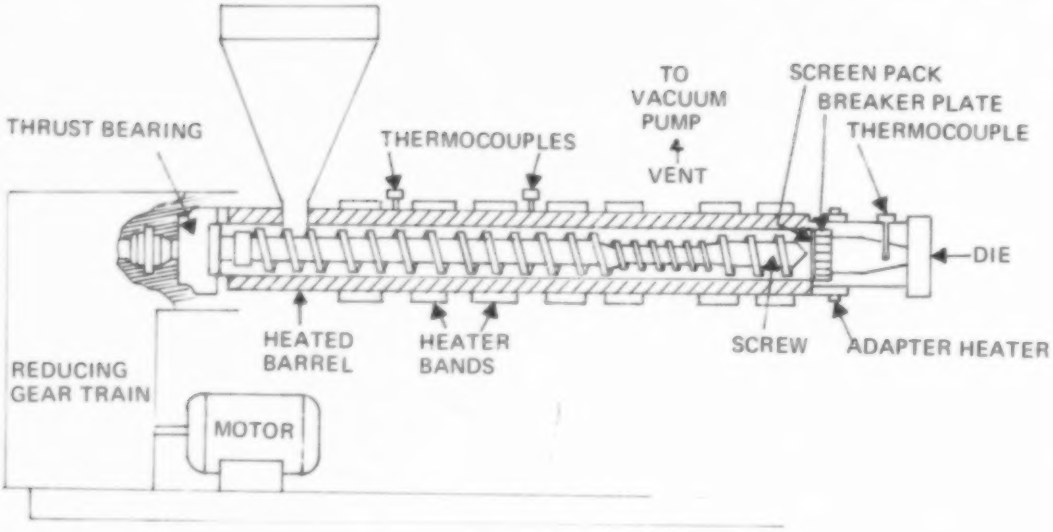

THRUST BEARING
THERMOCOUPLES
TO VACUUM PUMP
VENT
SCREEN PACK
BREAKER PLATE
THERMOCOUPLE
DIE
HEATED BARREL
HEATER BANDS
SCREW
ADAPTER HEATER
REDUCING GEAR TRAIN
MOTOR

Figure 11. Single screw vented extruder. The molten material is moved forward by the turning action of the screw building up pressure in the front end, which causes the extrusion of the molten material through the die in the form of a profile.

parts. The vent can be operated at atmospheric pressure, but the use of vacuum is a more common practice.

Film and Sheet Extrusion. Most film is made by the blown film process, which consists of extruding a tube of molten resin through a die with a thin annular (circular) opening (Figure 12). The plastic tube is expanded upon emerging from the die by means of internal air pressure, which is introduced through the center of the tube die. The bubble thus formed is cooled by an external air blast or by an internal cooling cylinder. The resulting film is then taken up onto rolls on a spindle type winding machine. If desired, auxilliary converting operations can be carried out prior to the winding station, for example, splitting, folding, printing, perforating, or forming into bags on continuous webs. Bags may also be individually packaged or spindled instead of being wound up in web form. Many of these operations are usually performed as separate conversion operations by outside companies, but sophisticated machines are rapidly incorporating these functions directly into the blown film extrusion line. Film thicknesses between 0.7 and 2 mils are most frequently used, and speeds of 100 to 300 feet per minute are common for this type production.

A small amount (10 to 20 percent) of film is produced by the slit die extrusion method. This product is frequently referred to as ‘‘cast film’’ to differentiate it from blown film. The slit die extrusion process involves extruding molten resin from an extruder through a wide slit die with adjustable lips into a cooling system, such as a water bath, or onto chilled metal rolls and then onto a windup stand (Figure 13). Rapid chilling gives better film gloss and clarity. The physical properties of cast film are also different from blown film: thickness variations are less, and cast film has a low degree of orientation as compared to blown film. Sheet plastics are also manufactured by slit die extrusion. The term ‘‘sheet’’ is applied to thicknesses greater than 0.010 inches.

For some applications varying degrees of orientation are desired. This is accomplished by stretching the plastic film under accurately controlled conditions to create molecular orientation (as discussed in ‘‘Orientation’’) and then locking this orientation into the film by fast cooling. This locked in energy can be released when the film is heated; the film then pulls back toward its original unstretched condition. This is the common ‘‘shrink’’ film of commerce. Another type of oriented film is the heat set film, which is obtained by holding the stretched film at a high temperature just below its melting point (heat set temperature). Such films have improved properties but are not normally shrink films, although they will shrink if reheated above the ‘‘heat set’’ temperature. Polyester films (Mylar) are good examples of this type.

Cast, blown, or extruded film is oriented by passing it over heated differential speed rolls where it is stretched in the machine direction. The advanced roll, traveling faster than the feed roll, causes the film to

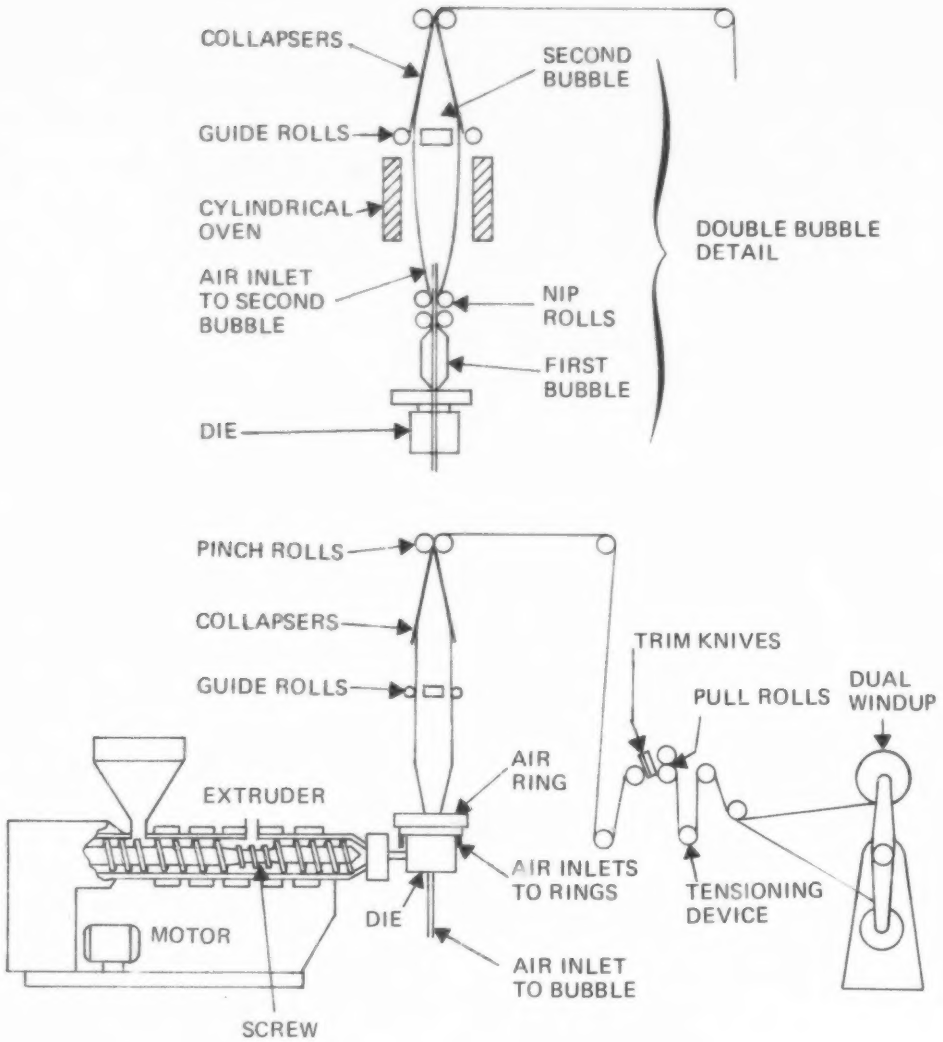

COLLAPSERS
SECOND BUBBLE
GUIDE ROLLS
CYLINDRICAL OVEN
DOUBLE BUBBLE DETAIL
AIR INLET TO SECOND BUBBLE
NIP ROLLS
FIRST BUBBLE
DIE
PINCH ROLLS
COLLAPSERS
TRIM KNIVES
GUIDE ROLLS
PULL ROLLS
DUAL WINDUP
AIR RING
EXTRUDER
AIR INLETS TO RINGS
TENSIONING DEVICE
DIE
MOTOR
AIR INLET TO BUBBLE
SCREW

Figure 12. Blown film processes. Blown plastic film is produced by extruding a circular profile (or tube) of molten plastic and applying air inside the tube to cause expansion of the molten plastic. After cooling, the plastic is wound into rolls as tubing or by slitting and trimmings, as single thickness film.

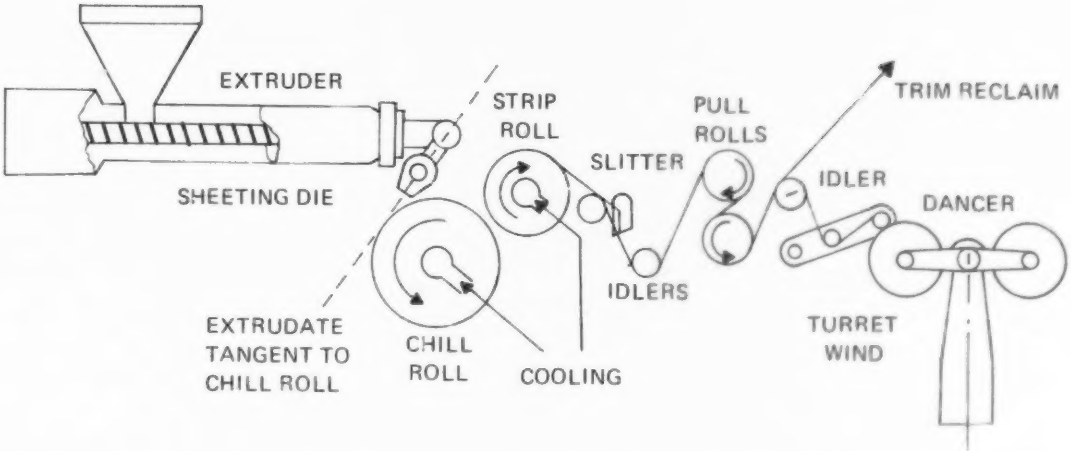

EXTRUDER
STRIP ROLL
PULL ROLLS
TRIM RECLAIM
SLITTER
IDLER
SHEETING DIE
DANCER
IDLERS
EXTRUDATE TANGENT TO CHILL ROLL
CHILL ROLL
COOLING
TURRET WIND

Figure 13. Film and sheet chill casting. Plastic film and sheet are produced by extruding molten plastic through a slit die and chilling it on rollers prior to final wind up.

thin down without substantially reducing its width. If the process is stopped at this point, the product is ''monoaxially'' oriented. To obtain ''biaxially'' oriented film, subsequent stretching in the transverse or cross machine direction is accomplished on equipment known as a tenter (stretching) frame, which consists of two endless chains equipped with gripper clamps and mounted on a ''Y'' frame and enclosed in an oven. Heat setting is usually accomplished at the exit end of the tenter frame.

Monoaxial orientation of blown film is obtained on conventional equipment by using heated differential speed rolls prior to wind up. Most blown biaxial film is produced by the double-bubble process (Figure 12). In this process, the film is blown into a small tube (or bubble), cooled quickly, and passed through pulling rolls known as nips. After passing through the nips, the tube is reheated to a temperature below its melting point and further expanded by internal pressure, while at the same time the longitudinal speed of the film is increased by another pair of pulling rolls.

Product Area. Blown polyethylene film is used extensively in packaging and for construction and agriculture applications. This film is used to make garment covers, household wrapping, and storage bags, etc. In construction, it is used as a wind breaker and to waterproof underground concrete structures. In agriculture, it is used for mulching, hot house glazing, storage covers, and in numerous waterproofing applications. Blown PVC film is used extensively as a meat and produce wrap, mostly in the unoriented form, but some monoaxially oriented PVC is also used. Clear non-shrink biaxially oriented polystyrene and polypropylene films are similarly used for many packaging applications. A typical high quality biaxially oriented film is the familiar ''Saran Wrap,'' which is a clear polyvinylidene chloride (PVDC) film.

Shrink wrap plastic packaging, which is produced by the conventional blown film methods described above, is a rapidly growing segment of overwrap packaging. Polyethylene, PVC, polypropylene and polyvinylidene chloride (Saran) are the most common films used for shrink wrapping. Other end uses include industrial palletizing, meat and produce wrap, and wrap for toys, games, records, newspapers and magazines, frozen poultry, six pack beer cans, and soft drinks, and numerous multipacks such as cosmetic sets and premium items.

The major plastics used in sheet extrusion are high impact polystyrene and ABS. Some polyethylene and PVC are also extruded into sheet. Polyethylene is mostly thermoformed into food containers and tote boxes, and clear PVC sheet is used for blister packaging. Other important uses for extruded sheet include signs, displays, refrigerator doors and panels, duct work, appliances, housing, snowmobile bodies, and some automotive parts.

Raw Material Requirements. All film processes require high quality compounds with a low melt index (stiff flow). Higher melt indexes are preferred for sheet extrusions. Any foreign matter in the compound, including high molecular weight resin particles or gel, can cause a bubble to break in the blown film process and a void or depression to appear in the slit die extrusion process. Furthermore, the particle size of all additives mentioned earlier are required for proper processing, and special additives are required to meet FDA food grade requirements for film used in contact with food products. Printing requirements on packaging film present additional raw material problems. For example, certain antioxidant and other additives have been known to inhibit the rate of ink drying.

Scrap Plastic Generation. Film fabrication generates a large amount of scrap plastic in the form of start up, tails, and reject film together with extruder purgings. In the production of polyethylene film this amounts, on the average, to 15 percent of production. Most is recycled by the fabricators who use as high as 25 to 30 percent regrind in standard film and up to 100 percent in applications such as construction and agricultural film. NP generation from polyethylene operation amounts to no more than 1 to 2 percent, mostly in the form of floor sweepings and badly contaminated rejects.

The fabrication of PVC film generates about 25 percent scrap. The larger PVC fabricators utilize most of their own scrap as regrind, and smaller fabricators usually sell the scrap to reprocessors. NP generation in PVC film fabrication averages 1.5 percent of production.

In the manufacture of polypropylene film, which is mostly oriented, as much as 40 percent of the production becomes scrap. The poor quality scrap is often bailed as film and solid to reprocessors, and the high quality scrap (about 25 percent of production) is repelletized for in-house recycling. The critical requirements of the orienting process limit the incorporation of recycled material to about 15 percent of the total. Thus, some of the pelletized scrap is also sold to reprocessors.

Handling reprocessed film scrap is difficult. Normally it is chopped into a ''confetti'' or fluff. This material can then be fed directly into the extruder using a special auger feeder, or it can be repelletized before mixing it with virgin resin.

Generation of scrap plastic in the fabrication of sheet can run as high as 40 percent of production. But most of this scrap is easily recycled, and NP amounts to about 1 percent of total.

Ability to Tolerate Nuisance Plastic. Film applications generally can not tolerate the melt viscosity variation and foreign contamination of most scrap from sources outside of the manufacturer's own shop. On the other hand, heavy agricultural and construction film can and does tolerate considerable amounts of scrap plastic. For NP to be utilized in these areas, however, the feed material has to be well mixed, uncontaminated with other resins, and subjected to heavy screening during reprocessing to eliminate particulate contamination (see section ‘‘Reprocessing’’).

Sheet materials, being thicker than film, can tolerate more NP. One possibility for using NP would be to coextrude a thick core material of NP with thin coatings of virgin material on each side. However, such sheet would be opaque and could probably not qualify for FDA approval.

Extrusion Coating, and Coating of Wire and Cable. The mechanical arrangement of slit die extrusion equipment readily permits coating to be carried out in line with extrusion. This can be accomplished by passing the substrate material over the top roll of a cooling stack and into the nip of the rollers along with molten resin from an extrusion die (Figure 14). A wide range of materials such as textiles, paper, nonwoven webs, plywood, and sheet metal are coated with plastic in this manner. The operation is referred to as extrusion coating or laminating. Thick coatings are most often referred to as laminates, and thin ones as coatings.

In the coating of wire and cable, the thermoplastic is extruded around a continuous length of wire or cable which passes through a cross head extrusion die. In a cross head die the material to be coated enters the die perpendicular to the initial direction of flow of the plastic. The coated wire is then wound on spools or drums after cooling.

Product Area. The most widely used plastic extrusion-coated product is the familiar polyethylene-coated paperboard used to manufacture the popular ‘‘Pure Pak’’ paper milk carton. Other related products are washable plastic wallpaper that has a clear coating of PVC extruded over the printed paper and some automotive and furniture fabrics which are produced by a one side extrusion of PVC onto a fabric substate. Waterproof tarpaulin and other fabrics are produced by the two side coating of fabrics. Many packaging films are also produced by extrusion coating of polyethylene or polyvinylidene chloride (Saran) onto such substrates as PVC, cellophane, acetate, polyester, aluminum foil, and paper.

Wire and cable uses range from thin coatings of polyethylene on military field wire to multi extrusions of several plastics in the manufacture of large diameter underground and high-voltage cables.

Raw Material Requirements. Most extrusion coatings require raw material specifications similar to those used for film and sheet extrusion. Because all coatings are thin, melt viscosity specifications are very critical. A small reject area in an extrusion coated product can cause the rejection of large rolls of the product, because commercial specifications usually limit the number of splices or cutouts permitted per roll.

Low density polyethylene is the major raw material used for extruded coatings on web substrates. Specific LDPE compounds with narrow

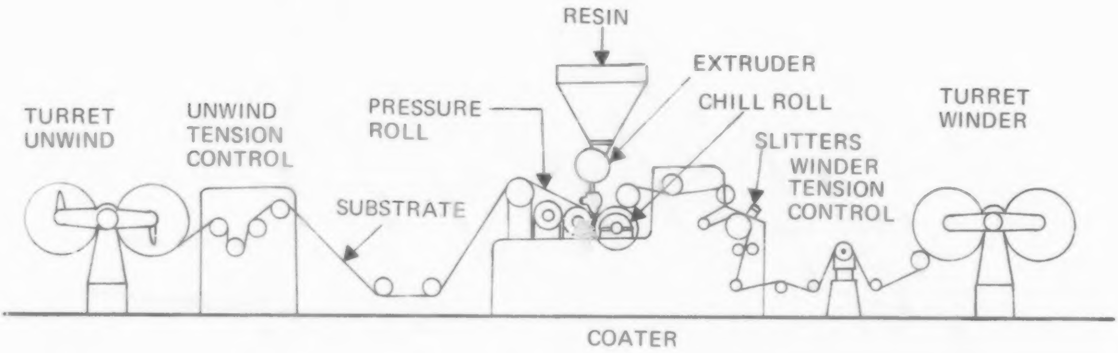

RESIN
EXTRUDER
CHILL ROLL
TURRET WINDER
TURRET UNWIND
UNWIND TENSION CONTROL
PRESSURE ROLL
SLITTERS
WINDER TENSION CONTROL
SUBSTRATE
COATER

Figure 14. Extrusion coating. A thin film of plastic is extruded from a slit die directly onto a substrate such as paper, cloth or metal foil followed by conventional wind up on rolls.

specifications of melt index, density, and molecular weight distribution are required to accentuate specific properties such as clarity, heat sealability, and the need for FDA approval. Other resins utilized for web coating include PVC, polypropylene, copolymers of polyethylene, and nylon. PVDC is usually emulsion coated, not extrusion coated.

Wire and cable plastic coatings require high electrical performance characteristics. Compound formulas are very exact, and little regrind is used even within individual shops having equipment suitable to handle it. Polyethylene and PVC are used most widely for wire and cable coatings; PVC dominates the market.

Scrap Plastic Generation. Wire and cable coating regrind often ends up as NP. Extensive efforts are currently being made by this industry to recycle metal (mostly copper) scrap. In this process, the reject coated wire is finely chopped, and the copper is separated from the plastic in an air stream, taking advantage of the difference in specific gravity between the metal and the plastic. The plastic portion, amounting to 5 to 6 percent of production, is disposed of as NP. In extrusion coating on paper board, NP levels average about 6 percent.

Ability to Tolerate Scrap Plastic. Due to the thin films used in extrusion coatings, it is doubtful that any NP could be utilized as a coating feed stock. Many wire and cable applications are unable at present to utilize scrap because of the technical difficulties; however, certain applications, such as TV lead wire, etc., can use scrap if it is free of metal contamination. Other applications are limited because the government has imposed restrictive specifications excluding secondary material (see Part V).

Pipe, Rod, Tubing, and Special Profile Extrusion. These articles are formed as continuous extrusions through an annular die approximating the desired profile. Cooling is usually effected by a water bath or trough. Sometimes an elaborate operation is required to shape the rough plastic from the die into the desired dimensions of the finished product.

Product Area. Pipe applications range from low specification drain, waste, and vent (DWV) pipe having no internal pressure requirements to those used for potable water in pressure systems. The resins used in pipe applications are PVC, styrene-rubber, polyethylene, and ABS, in the order of their poundage consumption.

Rod plastic, after being machined and cut, is used as parts of complex products ranging from simple housewares to complex appliances. Rods are available from plastic supply houses in sizes ranging from 1/8 inch up to 8 inches in diameter.

Plastic tubing is available in sizes ranging from small diameter dip tubes for aerosols and plastic bottles to garden hose. There is no distinct line of demarcation between pipe and tubing. A circular extrusion having one or more of the following properties: (1) small outside diameter; (2) thin wall; (3) flexible material; (4) no inside pressure is usually called tubing. Large diameter, rigid wall, circular extrusions for electrical conduit are also often referred to as tubing, yet they may be very similar in construction to the DWV pipe described above. Typical special profiles include house siding, automotive and building trim, lighting fixtures, window channels and ducts for electrical wiring.

Scrap Plastic Generation. The scrap generated during the extrusion phase of the manufacture of pipe, rod, tubing, and special shapes is similar to that from other extrusion processes. The amount of scrap that is reprocessed varies with the product, and color can be a problem. Most of the end uses for these products, however, require fabrication away from the site of extrusion. Because the volume is too small at any one location to warrant return to the extruder, the scrap from fabrication becomes NP. This can amount to 2 to 3 percent for most pipe end uses, to as high as 40 to 50 percent for parts machined from rod stock (including fabrication and converting).

Ability to Tolerate NP. For non-critical applications, pipe, rod and tubing offer good potential use areas for NP. This will be discussed in more detail in Part IV. The thick walls and typical dark colors presently marketed are complimentary to the processing of NP. Where a good exterior appearance is desired, coextrusion of an inside layer of NP combined with a virgin exterior is very practical. Currently, much PVC garden hose is coextruded using scrap plastic as an inner core. Special profiles used in many applications are dark colored and have heavy sections; this process area also can use NP. Again, the use of NP as an inner core is appropriate with profiles such as siding, etc.

Coextrusion. Profiles of all types are produced by coextrusion. As the term implies, the process consists of mixing two or more melt streams from separate extruders through one extrusion die. The melt streams can be different resins, different colors of the same resin, or different grades of the same resin. The technology of this process is very sophisticated, particularly in the design of the die and the use of different resins. In the coextrusion process the various melt flow conditions (temperature, pressure, speed) from the independent extruders must be carefully matched. Coextrusion is used to make film, sheet, foam, tubing, pipes, and coatings.

Product Area. Coextrusion of films is finding increased use in packaging applications. Their main attraction is the fact that they are manufactured in one step to produce a single web having the advantageous properties of two or more plastics, without the cost of secondary operation of coating or laminating. For example, polyethylene/polypropylene/polyethylene coextruded films are widely used in the packaging of snack foods, because the inner layer of polypropylene offers a low water vapor transmission rate and the outer layers of polyethylene have superior heat sealability.

Another important coextruded film is polyethylene/polyvinylidene chloride/polyethylene. This is used in large quantity alone or as part of a foil laminate for both gas and vacuum packaging of cheese and soluble coffee. The need for very low oxygen transmission in these applications requires polyvinylidene chloride.

Coextrusion is used in applications other than film. For example, white high density polyethylene and black polypropylene are currently coextruded into a heavy sheet and then thermoformed into containers for motor oil.

Scrap Plastic Generation. Most current coextrusion processes are unable to reuse their own scrap, because the scrap is a mixture. Scrap, which can range as high as 20 percent or more in individual processes, ends up as NP (9 to 10 percent is an average value). Much of this is concentrated in convertors' plants.

Ability to Tolerate Scrap Plastic. An important potential use of NP in this process would be to use it as a core material in a coextrusion with virgin plastic (or high grade scrap), where the latter material is used as the surface material. For example, three ply coextrusion processes could completely encapsulate NP in sheet, pipe, rod, tubing, and special profiles, except for the cut-off areas.

Blow Molding. There are two major types of blow molding in commercial use in the United States: extrusion blow molding and injection blow molding. Extrusion blow molding currently predominates.

Process. In extrusion blow molding (Figure 15) a hot plastic tube is extruded--usually vertically--between two halves of a female mold. The closing of the two mold halves completely pinches off the tube (or parison, as it is called) at the bottom and partially pinches off the top around the neck area of the bottle. Air is then blown through the inside nozzle of the extrusion die or a moving plunger through the neck of the bottle expanding the tube into the shape of the mold. Air also can be introduced into the tube via a needle which pierces the plastic tube in an area that is subsequently cut off in the finishing operation.

The molds consist of water cooled cavities, the periphery of which is either completely or partially sharpened to a knife edge. Mold halves are mounted on platens which are part of a clamping mechanism. When the mold clamps around the hot tube (called a parison), the knife edges of the mold seal the tube wherever they touch. After an appropriate cooling

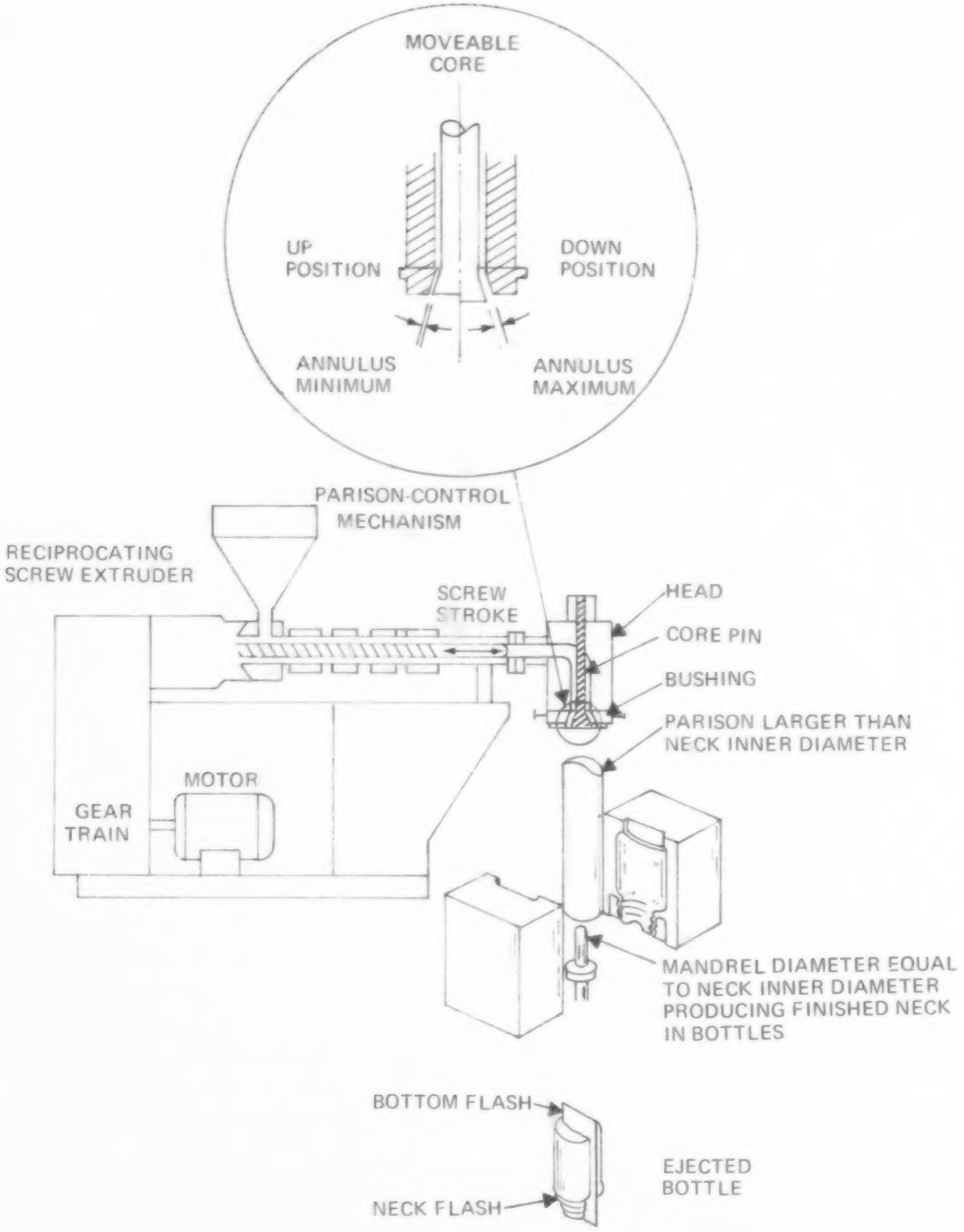

MOVEABLE CORE
UP POSITION
DOWN POSITION
ANNULUS MINIMUM
ANNULUS MAXIMUM
PARISON-CONTROL MECHANISM
RECIPROCATING SCREW EXTRUDER
SCREW STROKE
HEAD
CORE PIN
BUSHING
PARISON LARGER THAN NECK INNER DIAMETER
MOTOR
GEAR TRAIN
MANDREL DIAMETER EQUAL TO NECK INNER DIAMETER PRODUCING FINISHED NECK IN BOTTLES
BOTTOM FLASH
EJECTED BOTTLE
NECK FLASH

Figure 15. Extrusion blow molding. In extrusion blow molding a hot plastic tube is extruded between two halves of a female mold. The closing of the two mold halves pinches the parison at the bottom and partially pinches off the top. Air is blown through a nozzle or plunger inserted into the neck of the bottle expanding the plastic tube into the shape of the mold.

time, the mold mechanism opens and the product is removed. The portion of the original tube that remained outside of the knife-edged pinch-off is squeezed together and is still attached to the body of the blown part; however, the plastic at the knife edge pinch-off is thin enough to permit the excess material, called ''flash'' to be pulled off by hand or removed in a die stamping machine. Some blow molding machines have been developed to separate the ''flash'' within the mold before or during the opening process.

A cold tube, blow molding process has been made available from Europe. In this process, polyvinyl chloride tubes of a pre-determined diameter and length are produced by a standard extruder. The tubing is shipped to the blow molding location in cut form, and the tubes are automatically fed into a blow molding machine. They are dropped onto spindles mounted on a belt, which carries the tubes through a heating oven. When properly heated, the hot tubing and spindles enter a molding station where the tube is pinched off and blown into a finished bottle. The process as currrently practiced has many limitations, but new systems involving the cold tube principle are receiving serious attention. One important feature of this variation of the blow molding process is that it can produce biaxially oriented plastic bottles. The improved physical properties offered by orientation reduce the material requirements of the bottle by 20 to 35 percent, which offers the possibility of reducing the weight of plastic solid wastes.

In the injection blow molding process the parison is molded in a conventional injection mold (Figure 16). The test tube shaped parison is retained on the plunger or core rod of the injection mold and transferred into a blow mold which has the bottle shape. The injection molded parison, still hot from the original molding, is blown into the final shape of the die by allowing air to enter the parison through the core rod. The Cheeseborough Ponds Vaseline jar is made this way.

The injection blow molding process, in contrast to extrusion blow molding, is basically a no-scrap process. The entire mold charge is turned into a finished part during each cycle. Furthermore, orientation is also possible in the injection blow molding process.

Both extrusion and injection blow molding processes permit the manufacture of thin (even paper thin) and medium-thick wall constructions, but for very heavy walls (above 1/8 inch) blow molding is somewhat impractical. One of the limitations of blow molding is that this process provides limited control over inside dimensions. Lack of precise dimensional control is not detrimental in bottle construction, but it does introduce technical limitations in the fabrication of some industrial products.

Composite bottles can be produced by all blow molding processes. These techniques are still in the development stages but offer improvements

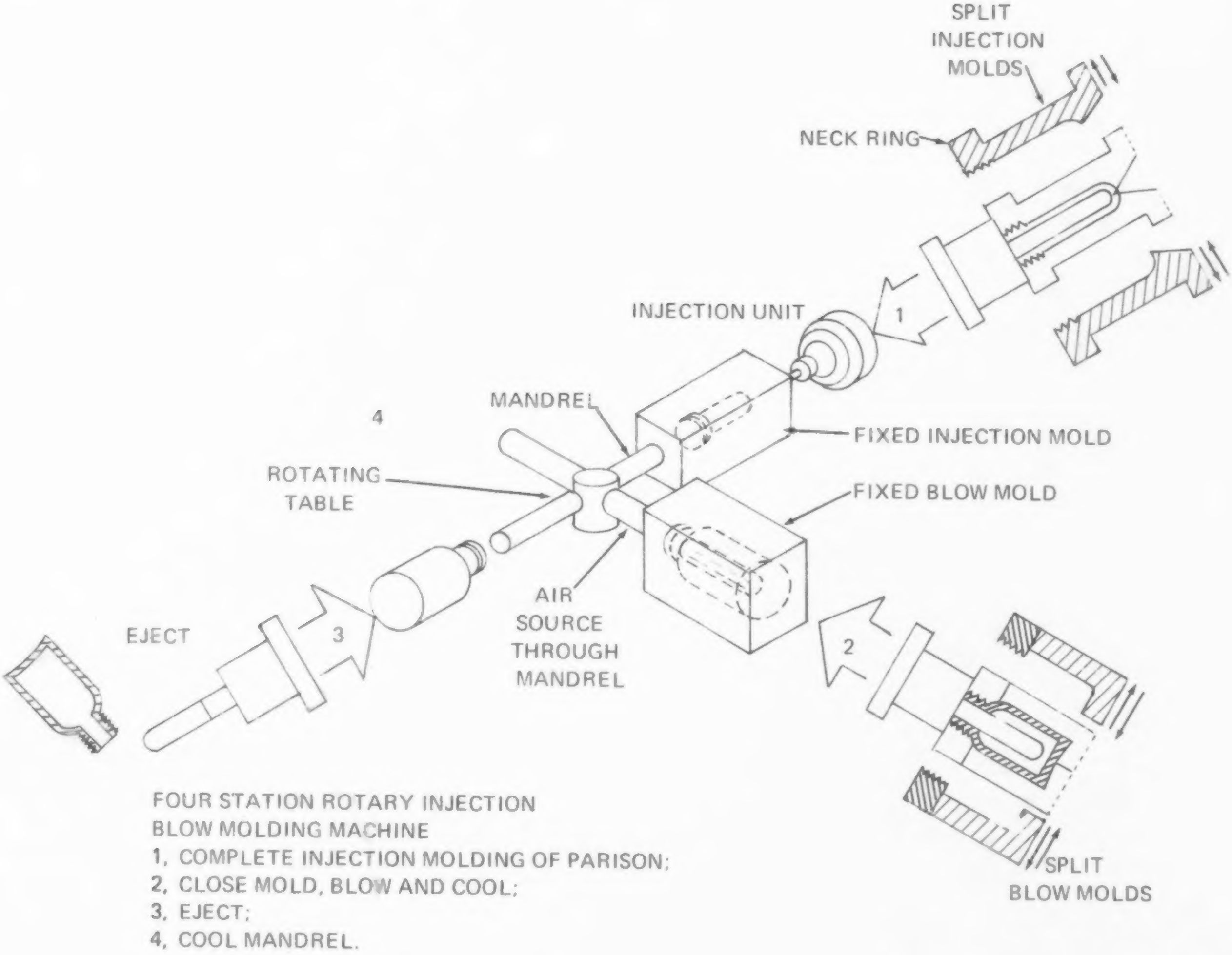

SPLIT INJECTION MOLDS
NECK RING
INJECTION UNIT
1
MANDREL
4
FIXED INJECTION MOLD
ROTATING TABLE
FIXED BLOW MOLD
AIR SOURCE THROUGH MANDREL
EJECT
3
2
SPLIT BLOW MOLDS
FOUR STATION ROTARY INJECTION BLOW MOLDING MACHINE
1, COMPLETE INJECTION MOLDING OF PARISON;
2, CLOSE MOLD, BLOW AND COOL;
3, EJECT;
4, COOL MANDREL.

Figure 16. Injection blow molding. In this process the parison is molded in a conventional injection mold at station (1). The test-tube-shaped parison is retained on the plunger of the injection mold and transferred into a blow mold at station (2), where the parison is blown to the final bottle shape and cooled. Final cooling and ejection takes place at station (3). Station (4) is used to cool the parison mandrels before the beginning of the next cycle.

in product retention in packaging applications; for example, an inner wall of PVDC can be used for an oxygen barrier and an outer wall of HDPE for strength.

The principal use of the blow molding process is for producing hollow shaped objects with ‘‘one or more re-entrant angles’’, e.g., the shoulder of a bottle shaped object. Some hollow objects (such as ordinary bowls and drinking cups) do not lend themselves readily to the blow molding process and are produced by injection molding. A bottle shape, on the other hand, could not be produced by injection molding because the steel plunger could not be removed around the re-entrant angle of the shoulder.

In comparing injection molding with blow molding, another very significant technical difference exists. Blow molding is accomplished at pressures of from 25 to 100 psi between the plastic and the mold surface. Injection molding requires pressures of from 10,000 to 20,000 psi to push the molten plastic through long, narrow passages. The reduced pressure of blow molding results in lower internal stresses in blow molded items.

Product Area. Approximately 80 percent of all blow molding is used to manufacture packaging items. Most of these are bottles or ‘‘bottle like’’ containers for the household. Some are industrial containers such as drums, carboys, and tanks. The household containers include bottles for cosmetics, toiletries, pharmaceuticals, chemicals, and foods such as milk.

The remaining 20 percent of blow molding is used to manufacture industrial products such as gas tanks, windshield wiper reservoirs, air ducts, visors for automotive use, floor waxer reservoirs, vacuum cleaner hose, hair dryer housings, lighting fixture globes, toilet floats, tool boxes, furniture seats and backs, christmas trees ornaments, and numerous toys.

Material Requirements. Practically any thermoplastic material can be blow molded: LDPE, HDPE, and rigid PVC are used in quantity in the blow molding of containers, toys, household, and industrial products. Lesser amounts of polystyrene are used. Blow molding today is expanding at a rate faster than that of the plastics industry as a whole.

Of all plastic materials, HDPE has been the workhorse of the blow molding industry. Extrusion blow molding requires a resin with stiff flow and a low melt index (0.2 to 2.0) and high molecular weight. The resulting parison must have a sufficiently high melt strength so that as it is dropped from the extrusion head it holds its shape prior to and during blowing. Blow molded items have the advantage of utilizing the low permeability, and high oxidation and ultraviolet resistance, etc., of higher molecular weight resins, as mentioned in the earlier discussion.

Melt viscosity control is very critical. Batch-to-batch and bag-to-bag variations can completely shut down a production line. Color control also is very critical. Lot-to-lot color consistency is required because in consumer packaging various lots are mixed on store shelves.

Blow molding permits a limited use of mixtures of resins. Some mixing of the polyolefins can be tolerated, but none of the other resins can be used as a mix. Incompatible resins (even different melt index material of the same resin) and degraded material and foreign particulate matter will cause streaks of varying thickness in the parison tube during extrusion of the tube.

Control of PVC blow molding is even more critical than polyethylene: specially designed screws and increased horsepower are required. PVC blow molding compounds contain more additives than HDPE compounds. This substantially increases the risk of migration of additives with subsequent subtle changes in flavor or odor (irrespective of the question of toxicity). Normally PVC must be processed in the blow molding operation at temperatures in the range of 390 to 410 F, which requires the use of high temperature stabilizers.

Scrap Plastic Generation. The extrusion blow molding process generates a large amount of scrap plastics which is proportional to the amount of ''pinch-off'' on a given part. The amount of SP depends upon the amount of excess width or length of parison that a particular molder might use. These two factors can be minimized by good engineering design. Products with a large percentage of pinch off (e.g., outdoor seats and backs, watering cans, handled bleach bottles) generate 25 to 40 percent SP.

Much of this SP is recyclable by regrinding. Regrind, however, can introduce contamination into the plastic part, and the molding properties of regrind change with every pass through the extruder. The percent of regrind in an end item must be carefully controlled, otherwise the product specification changes and, at worst, product control can be lost. In the latter case, it is necessary to purge the blow molding machine and start with new batches of material to obtain proper plastic melt balance to bring the process under control. Additional scrap nuisance plastics are created when control is lost. Generally, nuisance plastic generation is low, about 1 to 1.5 percent with the polyolefins, but as much as 5 percent with PVC. This NP consists of badly contaminated regrind, floor sweepings, and lumps from purging.

Ability to Tolerate Scrap Plastic. Because of the need for melt extensibility during the blowing phase, blow molding does not offer an attractive area for the use of highly mixed resins or NP. Any contamination--particulate matter, moisture, volatile hydrocarbons, or a variation in resin molecular weight--can cause fracture of the parison during the blow cycle.

A fractured parison produces a reject and repeated rejects create a loss of production control. Thus, only very closely controlled scrap plastic would be suitable for this process. However, if a sufficient volume of clean recycled materials (such as milk bottles) could be separated properly and cleaned of particulate material at a recycle refinery by multiple extrusion methods utilizing intensive filters (such as automatic screen changers), such material could be recycled in the blow molding process. Maintenance of color under these conditions could present a technical problem, but this might be solved by the development of products with low color requirements. The high temperature of extrusion should destroy bacteria and volatile hydrocarbons, and the screen pack should eliminate large size particulate matter. Some small sized particulate matter should be sufficiently encapsulated within the polyethylene to be non-extractable, therefore, primary recycling can become a reality in certain instances.

Rotational Molding. Rotational molding or rotomolding consists of tumbling or sloshing powdered or liquid formulas of plastic compounds in hollow molds through a heating and cooling cycle. Rotation is usually through 360 degrees on two axes (Figure 17). Some processes utilize less than 360 degrees on one axis by tilting or rocking the mold to obtain an even distribution of the compound. There is a common misconception that rotational molding utilizes centrifugal force to distribute the material throughout the mold but, in fact, the speeds of rotation must be maintained below the centrifugal point, otherwise the powdered resin goes to one spot and fuses in a lump.

The process usually consists of three steps: (1) a measured amount of compound is placed in a mold having a temperature below the softening point of the polymer; (2) the mold containing the compound is inserted in an oven where the material softens and builds up on the walls while the mold is rotated; (3) the mold is subjected to sudden cooling.

The thickness of the wall is determined by the amount of compound charged into the mold, and the inside of the part consists of a smooth surface roughly paralleling the contours of the mold. The walls are generally of uniform thickness, but thickness can be varied somewhat by either insulating sections of the mold to form thin wall or heating sections to increase thickness. The process normally produces details only on the mold side of the finished product. Textured, matte, or highly glossy finishes can be obtained.

Three major types of heating systems are used for heating rotational molds: air convection, salt spray, circulating oil. Heated air circulated in ovens by air blowers is the most widely used heat source. With this method one has to avoid overheating the mold, otherwise the plastic product is degraded. In salt spray heating, molten heat transfer salts are pumped through spray nozzles, and the melt is sprayed over the mold throughout

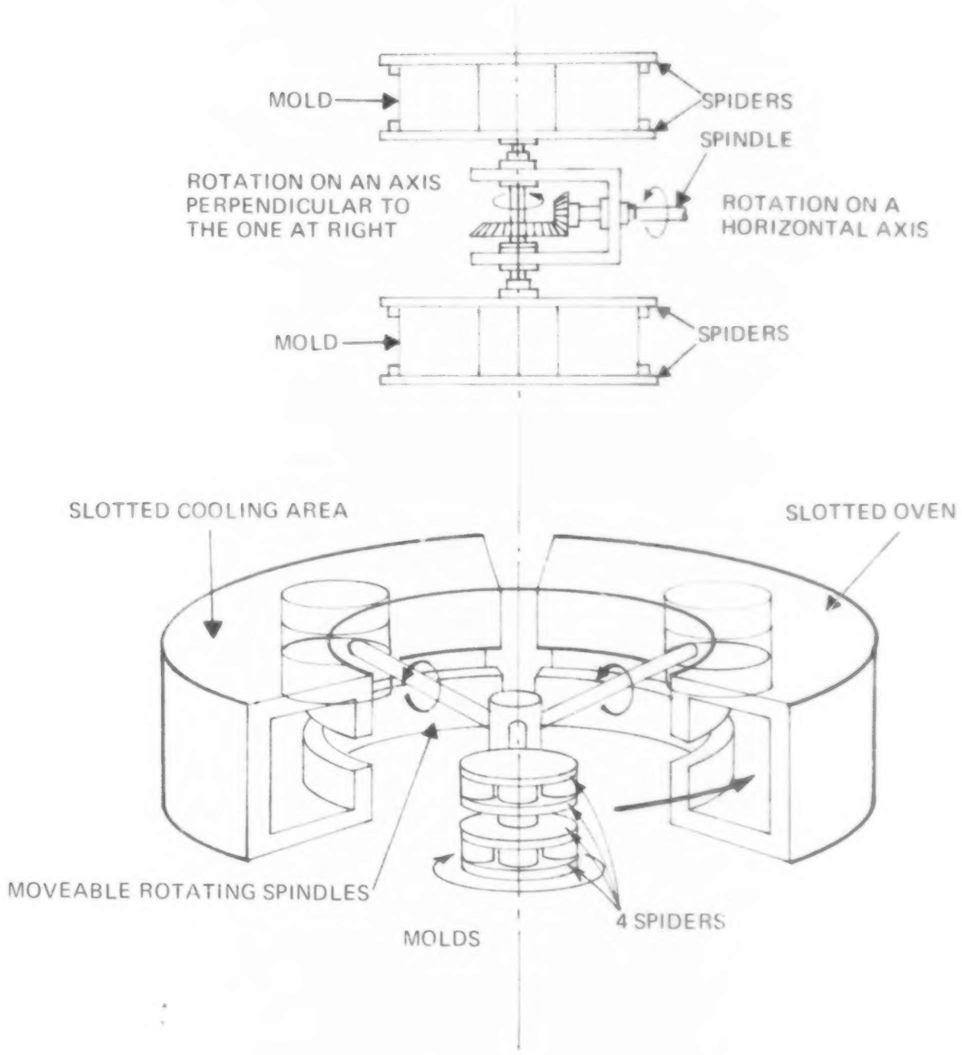

MOLD
SPIDERS
SPINDLE
ROTATION ON AN AXIS PERPENDICULAR TO THE ONE AT RIGHT
ROTATION ON A HORIZONTAL AXIS
MOLD
SPIDERS
SLOTTED COOLING AREA
SLOTTED OVEN
MOVEABLE ROTATING SPINDLES
4 SPIDERS
MOLDS

Figure 17. Rotational molding. Rotational molding consists of three steps: (1) a measured amount of compound is placed in a mold having a temperature below the softening point of the polymer; (2) the mold containing the compound is inserted in an oven where the material softens and builds up on the walls while the mold is rotated; (3) the mold is subjected to sudden cooling.

its rotational cycle. The rotational mold must be liquid tight at operating temperatures to prevent salt entering the mold and spoiling the finished part. Circulating oil is the newest process. This process eliminates the use of complex and expensive ovens and cooling stations and is used mostly for single cavity molds of large parts. It has the disadvantage that intricate parts with projections, ledges, protrusions, etc., are difficult to design for proper oil circulation.

The major advantages of rotomolding are: low mold cost and the formulation of strain free parts with controlled wall thickness. Rotational molding is particularly suited for the production of very large parts, size being limited only by the capacity of the equipment.

Product Area. Rotational molding is used for all sizes of products but is outstanding for the production of medium to very large size thermoplastic items. The process affords a high degree of flexibility: products varying from relatively simply cylindrical and rectangular shapes to highly irregular shapes incorporating compound curvatures can be produced. Rotomolding is particularly suitable for the manufacture of hollow bodies or items having re-entrant angles or undercuts and wall thicknesses greater than 0.030 inches. The process has an advantage over blow molding in that a uniform thickness can be produced on a very irregular shape without the detrimental ‘‘thinning down’’ of the plastic melt that is characteristic of blow molding. Blow molding can require as much as 25 to 35 percent more resin for a specific end item than rotational molding.

Rotomolding is economically attractive for: (1) short runs, (2) frequent color changes, (3) thick walls, (4) very large parts, (5) intricate designs. Typical rotomolded products (usually HDPE and LDPE) include tote bins, tanks for chemicals with a capacity as high as 1600 gallons, bins for storing food, machine guards, point-of-purchase displays, light globes, water and waste tanks, flower pots, hobby horses, apparel display forms, trash cans, and small gasoline tanks. Semi-hollow parts, such as garbage cans, can be molded by covering the top of the mold cavity with an insulating material which reduces or eliminates the deposition of molding material in this area. Plastisol rotomolded products include doll parts, squeeze toys, playballs, artificial fruit, syringe bulbs, automobile sun visors and arm rests, lawn ornaments, duck decoys, bicycle seats, and auto battery water dispensers. These compounds can be used to produce simulated leather surfaces and flesh in toy dolls.

Raw Material Requirements. The first materials to be rotationally molded were vinyl plastisols. At molding temperatures the PVC and plasticizer combine to form a molten thermoplastic. It is important that no gases evolve when the change from liquid to solid occurs, because they would mar the appearance of the molded object by forming bubbles or other defects.

During the 1950's, low density polyethylene powders were converted into hollow items by rotomolding, and during the 1960's powders of high density polyethylene, polystyrene, nylon and other thermoplastic materials, including foam formulations were developed for rotational molding. Many plastic compounds are still specially ground to produce rotational molding powders; others are dry blends in their original powder form. PVC dry blending powders are used in rotomolding as well as PVC plastisols.

Compounds for rotational molding require special properties; for example, high flow characteristics (high melt index) are needed so that the material flows easily over the surfaces of the mold as the mold rotates. The preferred melt index for rotational molding HDPE is in the range of 5.0 to 10.0. Normal size pellets are too large for rotational molding. Powders with particle sizes ranging from 25 to 60 mesh are typically used, and particle distribution also can be very important.

Resin formulas for rotational molding require a narrow molecular weight distribution. The presence of both high and low molecular weight fractions causes difficulty. Low molecular weight materials melt at lower temperatures and, therefore, soften early in the cycle; high molecular weight fractions resist melting until the end of the cycle, thereby causing a grainy effect. Attempts to adjust the temperature of the oven to compensate for either the low or the high molecular weight fractions usually aggravates the problem.

The powdered compounds that are required for this process tend to pick up more moisture than pellets. Moisture absorbed or absorbed by the powder can cause trouble in the rotational molding process; therefore, careful storage of powders for rotational molding and overnight drying in a de-humidifying oven is required.

Scrap Plastic Generation. In rotational molding, discrete amounts of compound are charged into the molds for each cycle; generally no regrind is used. Some products produce scrap plastic, for example, some is obtained from the removal of open sections and small amounts of trim flash at a mold parting line or insert. Removed openings and product rejects are usually of good quality and can be reground for possible use in other processes. The quality of this regrind is not suitable for reuse in rotational molding due to its particle size and the presence of minor degradation and contamination.

The nuisance plastic generation rate for rotational plastics is 1 to 3 percent of production. This consists mostly of floor sweepings, badly burned or contaminated products (such as with salt). In small rotational molding shops, the accumulation of scrap plastic is too small for economic salvage; therefore, it ends up an nuisance plastics to the extent of an additional 1 percent.

Ability to Tolerate Scrap Plastic. The highly complex nature of the rotational process, particularly its requirements in special resin properties, makes it a poor candidate for scrap plastic. One area where NP might be used, if a foamed plastic mass from NP could be developed, is as filler for empty rotationally molded products such as rocking horses, etc., to provide a product with better rigidity, improved strength, and additional weight.

Compression and Transfer Molding. For many years a clean cut distinction existed in molding terminology--injection molding processed thermoplastics, and compression and transfer molding processed thermoset material. A small amount of thermoplastics has always been compression molded, but it is seldom publicized. A major breakthrough in the techniques of injection molding of thermosets in the 1960's (discussed under injection molding) make the distinction very much more difficult at present. The confusion is compounded by some of the new ''cold forming'' techniques such as forging, coining, drawing and stamping which also involve compression pressure to mold thermoplastics.

Process. In conventional compression molding (Figure 18), the molding compound, which consists of a liquid thermoset resin mixed with such fillers as woodflour, cellulose, asbestos, or glass fiber to strengthen or give other added qualities to the finished product, is put directly into the open mold cavity either in the form of bulk material or as a pre-heated ''biscuit.'' The mold, which is normally heated, is then closed, pressure applied, and the compound caused to melt and flow throughout the mold. The heated mold causes the thermosetting material to undergo a chemical change which permanently hardens it into the shape of the mold. The three compression-molding factors--pressure, temperature and time the mold is closed--vary with the design of the finished article and the material being molded. It is common to degass the mold (opening and reclosing the mold about 1/8 inch after it initially closes) to allow volatiles developed during curing to escape. Improper degassing produces rejects, because bubbles are formed that result in weak sections.

In transfer (or plunger) molding (Figure 19), the thermoset molding compound is charged initially to a separate chamber or ''transfer pot.'' When the material is fully melted, a hydraulic ram pushes it through runners and sprues to fill closed mold cavities. Transfer molding is used in preference to compression molding for intricate parts, parts with very thin walls or small deep holes, and parts with inserts that might be damaged during the conventional compression process. The disadvantages of transfer molding over compression molding include: (1) additional equipment costs, (2) higher scrap rates, all of which are NP, (3) slightly slower cycles.

Some special forms of compression molding are pulp molding and pre-mix molding. In pulp molding, a porous form, approximately the shape of a

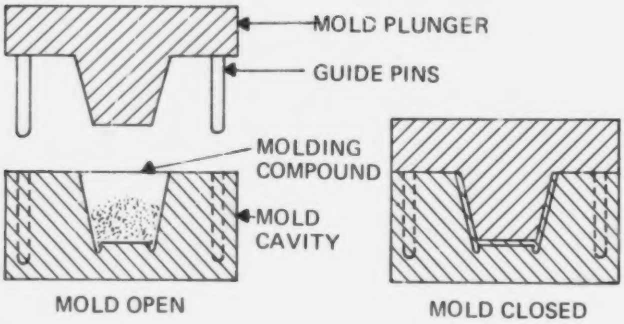
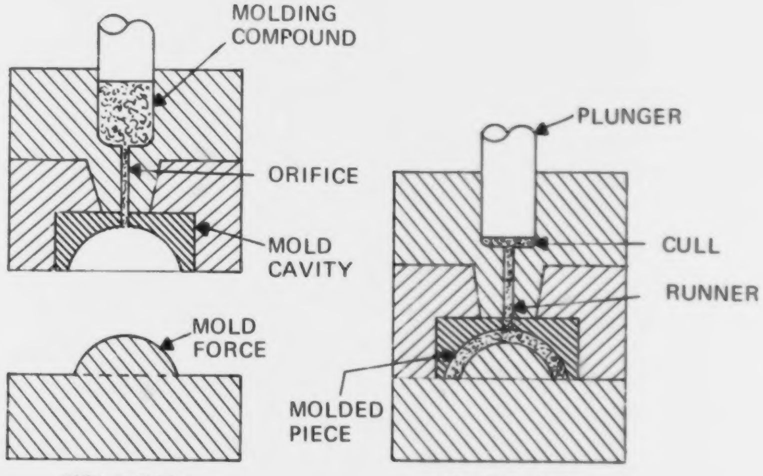

MOLD PLUNGER
GUIDE PINS
MOLDING COMPOUND
MOLD CAVITY
MOLD OPEN
MOLD CLOSED

Figure 18. Compression molding. In compression molding, the resin powder is put directly into an open heated mold. Heat and pressure from the closing of the mold melt the material and cause it to fill the shape of the mold.


MOLDING COMPOUND
ORIFICE
MOLD CAVITY
MOLD FORCE
PLUNGER
CULL
RUNNER
MOLDED PIECE

MOLD OPEN

MOLD CLOSED

Figure 19. Transfer molding. In transfer molding, a thermosetting material is softened in a separate chamber and pushed by plunger action from the hamper into a heated closed mold, while still in the molten stage. The product solidifies by chemical reaction within the mold, after which it is ejected while still hot.

finished article, is lowered into a tank containing a mixture of pulp, resins, and water. The mixture is then drawn through the porous form by vacuum, and when a sufficient thickness of pulp has been drawn, the pulp preform is removed and molded into final shape by conventional compression molding. In pre-mix molding, long fiber material such as chopped fiberglass is mixed with liquid thermosetting resins.

Molded thermoset parts, as they are removed from the mold, have a degree of flash or excess material which escapes from the mold cavity during molding. Usually this cannot be recycled. This flash is removed by hand or by tumbling the molded parts. NP generation in compression and transfer molding is 2 to 5 percent of production.

Ability to Tolerate Scrap Plastic. In its present form, thermoset compression and transfer molding processes could use NP only as a filler material. However, it is conceivable that products and formulas could be developed utilizing NP thermoplastics combined with fillers and/or liquid thermosets in compression or transfer molding similar to pulp and premix molding.

Dip and Slush Molding. Slush molding is a process used to produce thin walled flexible products. Usually plastisol PVC is the raw material. In slush molding, a hollow mold of the proper contour receives an excess charge of the liquid plastisol. Heat applied to the mold changes the liquid suspension of resin and plasticizer to a solid solution on the heated mold surfaces. Because heat transfer through the suspension is poor, only the material at the mold surfaces is converted to solid. Excess material is dumped out and used again. Frequently, several coatings are required to produce the finished product. In some cases the last coat is a foamed plastisol to simulate, for example, a foam rubber or felt lining in a finished overshoe.

In the dipping process plastisols are coated onto the surface of products (particularly metal) by dipping the article into the plastisol solution and then drying it in air or in an oven. The product to be coated is usually pretreated to enhance adhesion of the plastisol. Products such as handlebar grips are produced by dipping onto mandrels treated to permit release of the plastic.

A similar plastic coating technique is that of thermofusion or the molding of plastic powders. When a steady stream of air is introduced under controlled conditions into the bottom of a column of powdered compound, the resulting mixture acts very much like a liquid. Hot items can then be dipped into this mixture, known as a ‘‘fluidized bed,’’ to obtain coatings directly from the powdered compound. Oven fusing is usually required to finish the process.

Product Area. Slush moldings of PVC plastisols are used extensively to produce plastic overshoes, rubbers, bathing caps and similar products. Dip molding is used to produce skin-like products such as gloves. Both liquid plastisols and solid plastics (particularly polyethylene and nylon) are used to coat metal furniture and household items such as dish drainers, scissor-handles, etc.

Raw Material Requirements. The specifications for plastisols for both slush molding and dip coating are similar to those used in rotational molding. Powders used for fluid bed coating are also similar to those used in rotational molding and have similar specifications.

Scrap Plastic Generation. The dip and slush molding process utilize discrete amounts of material in the operating cycle. There is no predetermined amount of cutoff requiring regrind considerations. On the other hand, in both processes with both liquids and solid compounds, the material is handled over and over before being consumed as a final product. In slush molding the liquid goes in and out of a mold. In dipping, the mandrel or product form goes in and out of a central storage area of raw material. The potential for contamination resulting in rejected parts is great in these processes. But in reject form the contaminated batches still represent a high grade of scrap plastic, and much of it is sold for use in other fabricating processes. These processes generate approximately 3 percent NP.

Casting. An essential difference between casting and conventional molding is that little or no pressure is used in casting. In casting, the molten plastic or the fluid monomer is poured into either open or closed molds, cured at varying temperatures, depending on the compound used, and removed. Casting may be employed using either thermoplastic or thermosetting materials to make special shapes, rigid sheets, film and sheeting, rods and tubes. Thus, both finished and semi-finished products can be made by this process.

One of the best known casting techniques is monomer casting (often known as potting). In this process, liquid monomer plus a catalyst is poured into a mold and around the material to be encapsulated (potted). The resin is then allowed to polymerize either at room temperature or in special ovens. Continuous casting of film and sheeting is also done on an endless metal belt. Monomer plus a catalyst or polymer in solution is spread to the desired thickness on the belt as it moves through an oven. When the reaction is complete, the film or sheet is stripped off the belt and cut.

An important commercial process is the casting of thermosetting polyurethane foam. In simplest form, two liquid components are mixed and stirred in a container and a measured quantity of the mixture is then poured into an open mold where foaming takes place. The reaction is complex, and control over the properties of the final product is subject to a great many pitfalls related to variations in temperature of the components, humidity of the ambient air, mixture ratio of the components, mold design parameters, and accuracy of mold filling.

Product Area. The best known end products of casting are the sheets of transparent and highly colored methylmethacrylate plastic, well known as Lucite and Plexiglas. The transparent materials are widely used as unbreakable glazing and decorative constructions, and the colored sheets are used for thermoforming outdoor signs, particularly those with inside illumination. And today urethane castings are rapidly becoming popular as substitutes for wood carving in furniture and other conventional wood consuming products. Polyester casting resins (which do not foam) are also popular for wood substitute products and simulated marble. Potted (or encapsulated) electrical parts are widely used in the electronics and related fields. Also, many familiar hobby products such as rare coins, insects, flowers, etc., are cast in plastics for display purposes.

Raw Material Requirements. Methylmethacrylate monomer is the most widely used for thermoplastic applications; small amounts of styrene and nylon monomers are cast for special end uses. When thermoset materials are needed, the urethanes, epoxies, and polyesters are heavily used--not only as castings for wood substitutes but also for potting. All of these raw materials are liquid initially, and they undergo polymerization during casting.

Scrap Plastic Generation. Scrap from major thermoplastic casting operations is reground and used for special injection or compression molding products. Where special end uses have not been found, the scrap becomes NP. As expected, scrap from thermoset casting processes can not be reused. It all ends up as NP. NP amounts to 3 to 5 percent of the total volume of material cast.

Ability to Tolerate Scrap Plastic. Because all casting processes involve a basic non-reversible chemical reaction, no NP can substitute for the basic monomer. Potentially, the only use area for this NP would be as a filler or perhaps a composite product yet to be developed.

Calendering. Calendering can be considered a very special type of extrusion. It is used mostly to produce PVC sheeting and film and similar web products.

Process. In calendering, the plastic compound is passed between a series of three or four large, heated, revolving rollers which squeeze the material into a sheet or film (Figure 20). The thickness of the finished material is controlled by the space between the final rolls. In

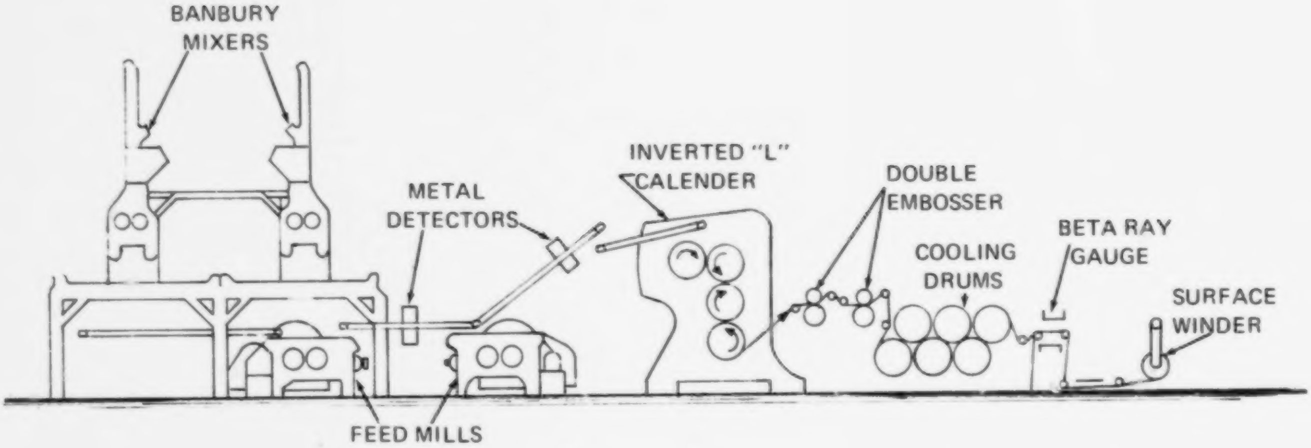

BANBURY MIXERS
INVERTED "L" CALENDER
METAL DETECTORS
DOUBLE EMBOSSER
COOLING DRUMS
BETA RAY GAUGE
SURFACE WINDER
FEED MILLS

Figure 20. Calendering. In this process, plastic resin is first mixed with additives in high shear Banbury mixers. The material drops from the Banbury in a semi-plastic state and is fed between the rolls of the calender where it is pressed into sheet form.

this process the surface of the film or sheeting may be smooth, matted, or embossed, depending on the surface of the final rollers.

The calendering process usually utilizes a separate high shear mixer such as a Banbury mixer (described above) to plasticate the material prior to the calendering step. The material is then dropped from the mixer or otherwise conveyed into the feed rolls of the calendering stack. As the feed rolls turn, they, in effect, extrude the plastic into the nip (where the rolls meet) of the calender rolls.

Calendering also can be used to coat thermoplastics onto textiles or other supporting materials. In applying a plastic coating to a fabric or other material by the calendering process, the coating compound is passed through two top horizontal rollers on a calender, while the uncoated material is passed through two bottom rollers. The product emerges as a smooth film which is anchored to the substrate when substrate and film pass between the same rolls.

Product Area. In addition to providing a product of high quality, the calendering process is very economical for very high volume production. Because of this very high volume requirement, few end uses can use the calendering process. The main product made on calender equipment is vinyl sheeting and coated vinyls, especially coated fabrics that are used for upholstery. The vinyl film and sheet are used in the manufacture of inflatables, footwear, purses, raincoasts, tablecloths, etc.

Raw Material Requirements. PVC is the principal resin used in calendering operations, and it is used for products ranging from thin packaging materials 0.002 inches thick to floor tiles 1/8 inch or more in thickness. The process can handle a wide range of variations in resins, but batch-to-batch variations fed to the calender rolls must be consistent, particularly for thinner gauge sheet and film. For example, variations in resin flow characteristics can produce an uneven thickness. The intensive pre-mixing which occurs in the Banbury mixer prior to feeding to the calender rolls can accommodate some variability in resin viscosity, providing the final mix meets the product specifications. Any contamination of the compound with particles, whether foreign or in the form of polymer gels, can result in objectionable pimples, if the product is a thin sheet.

Scrap Plastic Generation. Scrap plastic is generated in this process in the form of drippings from the mixers and the calender, and trim, tails, and front-end strip from the calender rolls. Typically, no attempt is made to recover the drippings or badly contaminated or damage sheet or film. This becomes NP. Levels of NP in this operation are usually less than 1 percent, if the product is an unsupported sheet.

Scrap from the calender is normally reused, and as much as 30 percent can be recycled; however, if the product is a coated substrate, such as a coated fabric, then the trim and scrap from poor starts can amount to 6 to 7 percent. This scrap is not easily recycled because it is a composite; it becomes NP.

Ability to Tolerate Scrap Plastic. The manufacture of floor tile utilizes a considerable amount of scrap plastic today. However, as mentioned above, this scrap has to be free of contamination with particulate matter. In addition to destroying the smooth surface of the tile, particulate matter could conceivably damage the expensive chrome-plated calender rolls. However, a calendering process using less expensive rolls could perhaps use some contaminated feed stock to produce a heavy sheet of plastic having a rougher surface than commercial floor tile. This product might be used for wall covering and similar applications.

Cellular Plastics. During World War II, attempts to produce lightweight bulletproof flotation material for boat hulls, buoys and floats lead to the development of expanded polystyrene (EPS). After the war the process was commercialized for producing 3-dimensional consumer products.

Process. The process of producing 3-dimensional products of expanded polystyrene foam is also commonly referred to as ‘‘chest molding.’’ In this process, beads of polystyrene containing a blowing agent are heated slightly by the molder in a pre-expander so that they are partially expanded before they are introduced into a closed mold. This ‘‘pre-expander’’ is basically a steam chamber with mechanical agitation. Pre-expansion of the raw material is adjusted to a density close to the density of the finished part. When the foaming action takes place the expansion volume goes into the holes and voids within and around the resin pellets.

The injection molding process (with modifications) also can be used to produce foam structures of polystyrene and other plastics. This variation is generally referred to as ‘‘structural foams.’’ Cellular structures have been fabricated by other techniques, including extrusion, casting, and rotational molding. Injection molding produces cellular structures with specific gravities in the range of 0.3 to 0.7. In general terms, structural foam molding can be defined as a process in which gas is mixed with molten resin.

Because the structural foam process is most frequently used for molding thick sections, it is characterized by long cycle times. Some process variations offer the additional advantage of using relatively inexpensive tooling compared to conventional high pressure injection mold tooling. These low pressure systems, however, do not produce as good a surface skin as can be obtained by high pressure systems. Most thermoplastic resins have been foamed by these techniques. Thus far, impact polystyrene is the most commonly used resin in the manufacture of structural foam. The capital investment in equipment for this process is comparable to that of conventional injection molding. The structural foam processes offer the usual advantages of injection molding (low labor cost, continuous reliable production), but with the added potential for making thick, bulky, lightweight parts with less material. The processing costs are usually considerably lower than those for conventional injection molding.

Three types of blowing agents used to provide the gas for expansion: (1) solid agents ranging from expensive azobisformamide to low-cost bicarbonate of soda, which decompose at injection temperatures to give gaseous decomposition products; (2) normally liquid agents (like pentane) which vaporize at injection molding temperatures; (3) gaseous agents such as nitrogen. The solid chemical blowing agents are used most frequently because of their convenience.

Product Area. Expanded polystyrene foam, while fairly new, is rapidly becoming a volume item for meat, fruit, and produce trays, egg cartons, and as industrial packaging material. Vending machine cups are also a large volume use, as mentioned in the section ‘‘Polystyrene.’’ In the form of foam-board, polystyrene foam is used as side wall and roof insulation in buildings. Thin sheets of polystyrene foam are laminated in tar paper for use as inexpensive insulation material, and a loose spaghetti-like form is shipped partially expanded to be fully expanded in the field as a low cost, extremely low-density cushion-packing dunnage material. Special extruded shapes are also produced for use as dunnage. Most dunnage ends up as NP, when the package is unpacked.

In still another packaging application, pre-expanded styrene foam beads are mixed with an adhesive and blown around a fragile product after it has been encased in a polystyrene film bag and set into a corrugated paperboard box. Thus, the beads can be made into an effective cocoon-like cushioning layer for packaged products.

In furniture applications, expanded polystyrene can be made into chair shells that are inexpensive and compete with wood and metal shells. ABS expansion molded shells are too expensive for consumer or commercial seating, but are used for high performance seating such as airplane pilot ejector seats.

Because of its buoyancy, polystyrene foam is used extensively by boat manufacturers to replace airtight compartments, and by manufacturers of life rafts, aquaplanes, swimming rafts, navigation buoys and floating docks. It is also used in refrigeration and air conditioning appliances, as drip trays, compartment separators and section insulation, toys, novelties, displays, housewares, portable coolers, counter displays, carvings, signs, christmas ornaments, and floral displays.

Raw Material Requirements. Resin requirements for molded foam applications are very similar to those for high quality injection molded products.

Scrap Plastic Generation. EPS molding utilizes a discrete amount of material for each shot, a practice that keeps scrap plastic generation to a minimum. On the other hand, the expandable pellets are very light and difficult to transport. Spillage is very visible and difficult to dispose of.

The light weight of the finished EPS product makes regrinding and reuse difficult. If one molds thick articles, one can regrind the scrap and incorporate between 10 and 15 percent. On the other hand, if one molds a thin walled product, no regrind can be incorporated. Thus, in molding foamed polystyrene between 5 and 10 percent ends up as NP.

Most extruded sheet foam processes use front end injection of blowing agents with general-purpose polystyrene as the raw material. In this process, foam can be reprocessed in the extruder. If the extruder is also the thermoformer, as the majority now are (see section below ''Thermoforming''), the scrap from thermoforming can be (and is) reprocessed. If the sheet is made from expanded beads, one can sometimes grind some of the scrap and use a crammer to put it back into the extruder; however, this is not the usual practice. Here, NP generation can increase to 10 to 15 percent of production.

Ability to Tolerate Scrap Plastic. The EPS and sheet extrusion processes are sensitive to the quality of raw material, particularly the amount of blowing agent incorporated. The use of scrap plastic is these processes does not appear attractive. The structural foam process, however, could potentially use NP for low-cost, low-specification wood substitute products, for example, single-trip shipping pallets.

Converting

Converting operations transform semi-finished products to finished ones by thermoforming, laminating, coating, bag making, printing, and post-forming processes. Many conversions involve several operations. Often these are carried out by the fabricator either in line with the basic fabricating process or in separate converting areas contiguous to the fabrication process.

Thermoforming. The thermoforming process is a post-forming process for extruded sheet; both solid and foam sheet are used. The basic process (Figure 21) is as follows: (1) preheat the plastic sheet; (2) position it over a male or into a female mold; (3) by vacuum, pressure, and/or mechanical action cause the sheet to take the form of the mold. Excess material is then trimmed off to obtain a finished product. When the force is obtained by vacuum, the process is known as ''vacuum forming,'' and when higher pressures are required, they are obtained by sealing a chamber to the opposite side (usually the top side) of the sheet, and

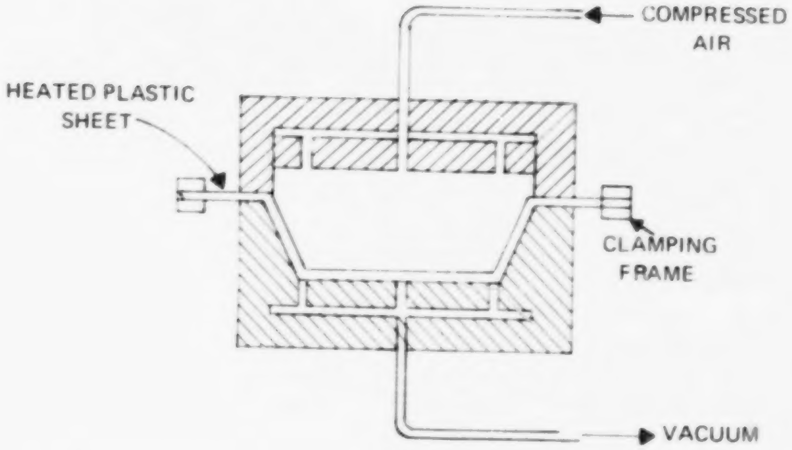

COMPRESSED AIR
HEATED PLASTIC SHEET
CLAMPING FRAME
VACUUM

Figure 21. Thermoforming. The basic thermoforming process consists of the following steps: (1) preheat plastic sheet; (2) position the sheet over a mold; (3) bring the sheet into contact with the mold by the use of vacuum between the mold and the sheet and/or pressure above the sheet.

building pressure within the chamber with compressed air. This system is known as ''pressure forming.'' Vacuum and pressure forming are variations of the same basic technique, even though the difference in the formed parts may be significant.

Thermoforming cycle times are short, and this is a major attraction of the process. Other advantages are the ability to obtain extremely thin walls, and the ability to use a wide range of production levels. The major limitation in the cycle time is the thermal conductivity of the plastic itself during the cooling cycle. As an example of the high speed production capability of this process, cottage-cheese tubs (16 oz) are produced in 20- to 30-cavity molds in 2- to 3-second cycles. The entire production is automatic, from roll stock to the finished carton ready for final shipping.

Thermoforming also is used to produce blister packages. A blister is formed in the shape of the item to be packaged, but slightly oversize to provide room for the product. Plastic materials such as acetates, butyrates, vinyls and oriented polystyrenes are usually used to produce the blisters. After they are formed, the blisters are trimmed and placed into fixtures, and the parts to be packaged are placed inside the blisters. Pre-coated cards are then sealed to the blister using heat and air pressure.

Thermoforming is also the processing technique used in skin-packaging operation, which have found a wide variety of uses in the shipping and handling of fragile items. The skin-pack process utilizes strong flexible films such as vinyl or polyethylene and/or film laminates in combination with corrugated cardboard or chipboard paper products. In this process the articles to be packaged are placed onto the paper product, which is then placed in a machine where the plastic film is heated and drawn down by vacuum around and over the items to be packaged. At the same time, the plastic adheres to the paper. Thus, in skin packaging, the item to be packaged becomes the mold, and it is enveloped in the plastic film. Expensive forming tools are not required.

Product Area. Thermoforming competes directly with injection molding in several areas. But each product--in fact, each product variation--has its own requirements. Thus, impact-polystyrene cottage-cheese containers, which are opaque to hide the appearance of the cheese curd, are thermoformed; whereas transparent containers for ice cream or candies require crystal polystyrene, and these are usually injection molded. Transparent, biaxially oriented polystyrene sheet (the only sheet form in which clear polystyrene is available) is difficult to thermoform and therefore costly. Conversely, injection molding of opaque, thin wall, impact polystyrene containers could not compete economically with thermoforming.

In areas where blow molding and thermoforming are both capable of producing a similar and competitive product, the advantages of thermoforming are: (1) increased throughput per dollar of investment, (2) processing stability. Although the thermal problems of producing uniform plastic sheet plus thermoforming are considerable, they are less troublesome than those of blow molding.

Principal areas of application of thermoplastics are in the mass production of rigid, thin wall containers, and in blister and skin packaging. Cigarette packages, thermoformed cottage-cheese containers, foamed-styrene trays, and single-service drinking cups are typical examples. Some of the more recent new product areas are thermoformed oil cans, foamed polystyrene egg cartons and the spin welched/thermoformed non-carbonated beverage bottles. High production rates, complete automation, minimal downtime and reject losses, plus extremely high scrap-recovery rates combine to make thermoforming the best available process for the manufacture of thin wall, simple shaped containers in high volume, when it is in line with the extrusion process.

Scrap Plastic Generation. One of the most difficult problems to overcome in thermoforming is control of trim. Both the amount of regrind and the amount of nuisance plastics are serious limitations of the process. Recycling is only possible if the thermoformer also fabricates the sheet. Otherwise the trim becomes NP, unless it is sold back to the sheet fabricator or to the reprocessor. Regrind averages 40 percent in many sheet fabricating operations. By careful layout and control of machine conditions, some cottage-cheese container manufacturers have reduced the amount of regrind to about 30 percent, and new processes are being developed that will reduce the volume of regrind further.

The range of scrap recovery rates in thermoforming is very wide, depending upon the details of the process, the housekeeping of the processor, and his ability to use or sell the scrap. In addition to scrap from trim, scrap is also generated in some processes from grinding rejects. Nuisance plastic generation rates as high as 8 to 10 percent are cited by some as necessary to the process, but the leaders in the field are believed to be keeping loss rates down to the 1 to 2 percent level. Use of beta-ray gauges and other processing controls has been important in establishing positive control over scrap recovery by controlling sheet thickness and, therefore, thermoforming accuracy.

Laminating. In the laminating process, multiply layers of resin and filler are combined to produce a final product. The most common example is high pressure decorative laminated sheet such as that sold under the well known tradename, Formica. This type of sheet is produced by pressing resin impregnated paper and other sheet materials (including an outside printed pattern sheet) in a hot multi-platen press. Thermosetting plastics are most generally used; they bind the reinforcing materials such as cloth, paper, wood, or fiberglass. In producing flat high pressure laminates (Figure 22), impregnated sheets are stacked between two highly polished steel plates and subjected to heat and high pressure in a hydraulic press. This cures the plastic and presses the plies of material into a single piece of the desired thickness.

High pressure tubing is produced in a similar process. Resin treated reinforcing sheets are wrapped, under tension and/or pressure, around a heated rod, and the assembly is then cured in an oven. In producing formed shapes, the reinforcing material is cut into pieces that conform to the contour of the product, fitted into the mold, and cured.

Whatever the final shape, the first step in high pressure laminating is to impregnate the reinforcing materials with plastics. Textile fabrics (particularly glass cloth) impregnated with thermosetting resins are contour laminated. Spherical structures of high strength are obtained by laminating continuous filament (usually glass fiber), which is precoated with a thermosetting resin, onto a mandrel. This process is called ''filament winding.''

Film lamination of one or more roll films is common for packaging end uses and is usually accomplished in conjunction with printing (see section ''Decorating Plastics''). Adhesive is applied to one side of the film at one printing station, and a second continuous film is brought into contact with the adhesive coated film before the films enter a set of nip rolls. The type of adhesive used in this process depends upon the individual substrate. For example, laminates of paper with plastic can use solvent based adhesives, because the vapors can pass through the paper; laminates of impervious material require the use of thermoplastic (hot melt) or thermoset adhesive formulas.

Product Area. The end product of high pressure laminating may be plain flat sheets or decorative sheets, as in counter tops, rods, tubes, or formed shapes. Contour laminating is used in the manufacture of boats, industrial tanks and similar large parts; plastic, or glass fibers and resin, or glass cloth and resin mixtures are either sprayed up or laid up to produce the product. The lay up type of glass fabric and plastic construction results in products which demand the ultimate in tensile strengths from plastic materials. Extremely high tensile strengths have been obtained by continuous filament winding of glass or other materials impregnated with a thermosetting resin, and they represent some of the strongest man-made materials available; in many cases they are stronger than the metals they replaced.

Laminated plastics are used for such items as automobile timing gears, cams, silent gears, clutches, fan blades, and bearings used in machinery. In the decorative field, resin treated wood surfaces and colorful

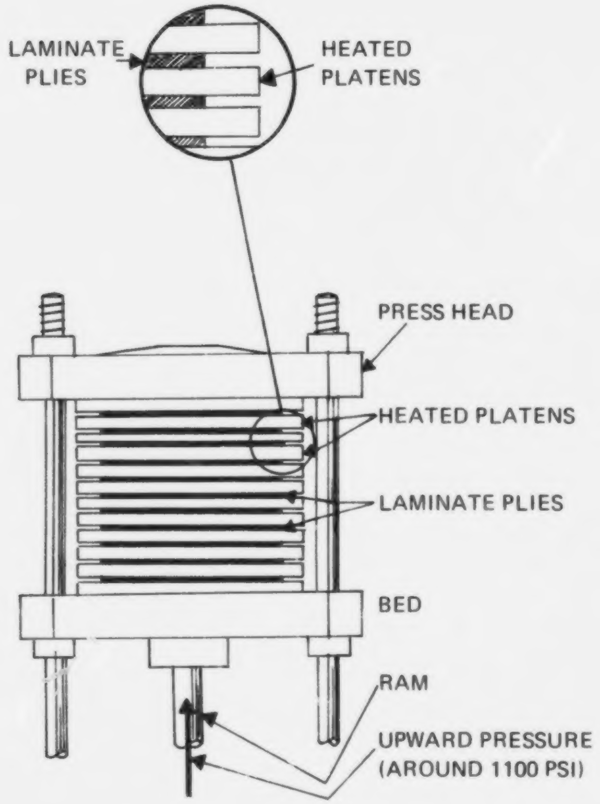

LAMINATE PLIES
HEATED PLATENS
PRESS HEAD
HEATED PLATENS
LAMINATE PLIES
BED
RAM
UPWARD PRESSURE (AROUND 1100 PSI)

Figure 22. High-pressure laminating. High pressure decorative laminates are produced by laying up sheets of resin, impregnated paper or other sheet material, and pressing them together in a hot multi-platen press.

fabrics are used to produce decorative table tops which are wear and mar resisting and impervious to many solvents; in the packaging field, film laminates are used for applications already described under ''coextrusion.'' Coextrusion and lamination can produce equivalent ''multiplastic'' films.

Scrap Plastic Generation. Scrap rates are high in high pressure lamination, and the scrap is not salvageable. Therefore, NP generation averages about 8 percent. Scrap rates are also high both in the production of film laminates and in their subsequent conversion into labels, bags, or other packaging material. Little, if any, side trim or scrap cuttings from laminates is suitable for recycling. Most of it ends up as NP. The lamination process itself generates 8 to 10 percent NP.

Ability to Tolerate Scrap Plastic. Laminating processes could be used to produce the multi-layer products previously mentioned, where NP is used as the core material overlayed with virgin or high quality recycled plastic.

Coating. Both thermosetting and thermoplastic resins may be used as coatings. They can be applied as a melt, a thermosetting liquid, a solution, or as a finely divided powder. A wide variety of substrates such as metal, wood, paper, fabric, leather, glass, concrete, ceramics, or other plastics can be coated. Methods of coating include knife or spread coatings, spraying, roller coating, dipping, and brushing. Calendering is also a form of coating and was described earlier. The method of applying plastic coatings to metals was described under ''Dip and Slush Molding.''

In spread (or knife) coatings (Figure 23), the material to be coated passes over a roller and under a long blade or knife. The plastic coating compound is placed on the substrate in front of the knife. The thickness of the coating is regulated by both the position of the knife and the speed at which the substrate is drawn under the knife.

In roller coating, two horizontal rollers are used. One roller picks up the plastic coating solution and deposits it on the second roller which, in turn, deposits the coating solution on the substrate. A plastic coating also may be applied by spraying it through a spray gun or by brushing it over the material to be coated, as in silk screen work.

Product Area. Vinyl plastisol coatings are used for coating fabrics to obtain materials not unlike old-fashioned oil cloth, waterproof tarpaulins, tenting materials, etc. Plastic coatings are also applied to the back of rugs to give them non-skid properties. Foamed or cellular vinyls are also used to coat fabrics. For example, vinyl foam with a non-foamed vinyl skin is used to fabricate winter jackets, upholstery material for furniture and automobiles and in ladies' accessories such as hats, handbags, shoes and belts. In the packaging area, Saran-coated films are widely used, as mentioned above, because Saran has good oxygen-barrier characteristics.

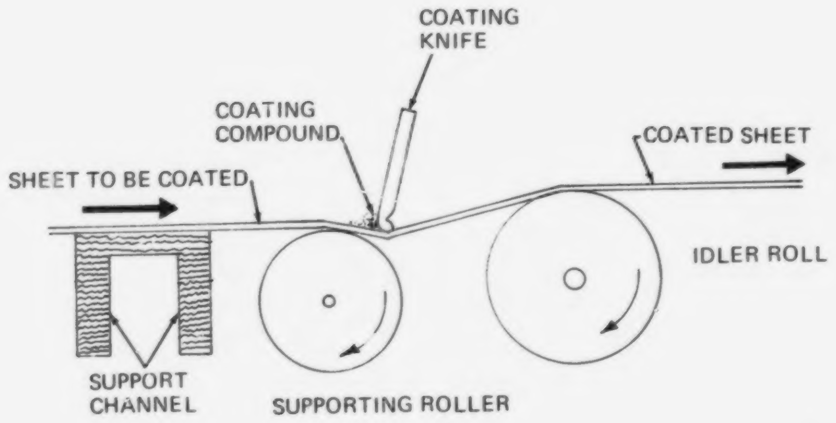

COATING KNIFE
COATING COMPOUND
COATED SHEET
SHEET TO BE COATED
IDLER ROLL
SUPPORT CHANNEL
SUPPORTING ROLLER

Figure 23. Knife coating. In spread (or knife coating) the material to be coated (substrate) passes over a roller and under a blade (or knife). The plastic coating compound is fed onto the substrate in front of the knife. The thickness of the coating is regulated by the amount of clearance between the knife and the substrate as well as the speed of travel of the substrate.

Because polyethylene has good heat sealability, it is often used as a coating on aluminum foil, which cannot be heat sealed.

Raw Material Requirements. Coating obviously involves thin layers of plastic, which makes resin requirements very demanding. Thus, molecular weight, and molecular weight distribution of the polymer are critical properties. The resins sold for this application are special formulas that command high prices. Stringent quality control is required by the resin manufacturer.

Scrap Plastic Generation. Because the end product is typically a composite or, in the case of coatings on a plastic substrate, a multiplastic, little of the scrap can be recycled. Thus, scrap from trim, start ups, rejects, etc., becomes NP. Levels of NP can vary from 6 to 10 percent.

Ability to Utilize Scrap Plastic. Due to the high quality of resins required for coatings, use of NP within the current processing technology would be difficult. However, a high quality plastic coating could perhaps be used to upgrade the surface of a plastic item produced from scrap plastic of poor quality.

Bag Making. Special bag making machines take films such as polyethylene or polypropylene and convert them into individual bags by folding, heat sealing, and cutting the film. In this operation finished bags are stacked or spindled for subsequent filling. While bag making is usually done by converters, recent developments have resulted in equipment which produces bags directly in line with the extrusion process at the fabrication level. Feed stock for form-fill-seal packages can be of a monoplastic, multiplastic, or composite construction. Scrap rates in both bag making and form-fill-seal equipment are high (4 to 6 percent), and little, if any, scrap is recycled. Most ends up as NP.

Post-Forming Processes. Plastic film and thin sheet is frequently converted into finished products such as baby pants, wading pools, toy inflatables, disposable gloves, novelty handbags, upholstery coverings, placemats, and other novelty products by cutting and heat sealing. Scrap rates are high, and little of the scrap is currently reprocessed due to the wide variation of colors, formulas, and consumption patterns. Much of this scrap is in the form of a composite. Thus, most scrap ends up as NP.

Heavy sheet materials are fashioned into three-dimensional objects by welding or by using nails, screws, and adhesives. Plastic tanks and ducts are typical products. Scrap generation is modest, but it is seldom recycled. Often some scrap pieces are retained as raw material stock (like lumber pieces) for a subsequent job. NP, where it exists, is present in small quantity, therefore collection is diffcult.

Sheet plastic is used for stamped washers and other two-dimensional products, and rod plastic is normally machined into three-dimensional products. Scrap cuttings from machining and stamping represent a relatively high percent of production, but it is dispersed in a number of locations and is usually badly contaminated with dirt, oil, and metal chips. Therefore, the potential for recycling this scrap is poor.

A new processing technique referred to as "cold forming" utilizes plastic preforms such as sheet, rod, or tubing to form finished products by techniques similar to those used in metal forming. With the exception of shotgun shells, which consume about 10 million pounds of very high molecular weight polyethylene, these processes are mostly developmental at the present time.

Decorating Plastics. Plastics are most commonly decorated by embossing, printing, and labeling. The latter process is probably the major one used for 3-dimensional products, and printing is almost the exclusive process used to decorate film.

Printing on Plastic Films. Some plastic films are easy to print, but many (particularly polyethylene and polypropylene) are inert to most commercial ink systems and, therefore, require special surface modification. The most commonly employed modification is surface oxidation by flame or by an electronic treatment. Both methods result in an oxidized surface layer which can be more easily wetted with ink. In flame treatment, the hottest portion of a flame contacts the film surface only for a very short period. Distortion and excessive softening of the plastic surface is avoided by passing the film rapidly over a cooling drum during the treatment. In the electronic treatment, which is the dominant process, the film is passed between two corono-discharge rods or between a metal roll connected to a generator and a corona-discharge shield. The corona discharge creates ions and radicals from the surrounding air that oxidize the film surface. Both sides of a film can be treated simultaneously, and it is usually done in line with the extrusion process. No surface treatment is required with polyester, polyamide, or PVC films, but they do require static eliminators and special ink systems. Cellulose acetate films print fairly easily without pre-treatment, but plasticizer compatibility is important in ink selection as the ink must be **highly** plasticized.

The two principal methods of printing on plastic film in continuous rolls are flexographic and gravure. Some problems associated with printing on plastic films are significantly different from those of printing on paper. For example, close register is important because plastic film is easily stretched, and accurate heat control is necessary with most oriented films, particularly the so-called "shrink films" which are more heat sensitive than cast films. Furthermore, to avoid blocking (sticking), the ink must be dried properly.

Printing on Three-Dimensional Plastics Products. Commercial processes used to decorate three-dimensional plastic products are: embossing, silk screen, offset, hot stamping, and spraying. Embossing is accomplished by the fabricator; both designs and text are reproduced from engraving in the molds. Color contrast is not as good as with ink decorating methods, but the result is legible and commercially accepted in many product areas. A major portion of printing and spraying also is done by the fabricators, and some is done by contract printers and packers.

A large percentage of printing is still accomplished by manually fed equipment, but the use of modern, fully automated equipment is growing rapidly. Significantly, automated euqipment, particularly in the plants of the plastic fabricator, tend to reduce the percent of rejects and the amount of potential NP.

Labeling on Three-Dimensional Plastic Products. Labeling is used almost exclusively on 3-dimensional products and is seldom used on film or sheet, except for price tags, etc. There are three major labeling processes of commercial significance--paper labels, pressure-sensitive labels, and transfer labels.

Paper labels are the cheapest and most widely used method of labeling 3-dimensional plastic products. These labels are usually adhered using air-drying adhesives or scotch tape and are affixed by methods ranging from hand application to high speed automatic labeling systems. Practically all paper labels are applied by the packer in line with the filling operation.

Pressure sensitive labels have the adhesive affixed to the reverse side of the label (such as scotch tape). The label substrate may be any film (paper, plastic, metal foil, etc.). These labels are difficult to attach; much is done by hand, although automated equipment is used in volume production end uses.

Transfer labels consist of two types--water transfer and heat transfer. Water transfer labels are the familiar ''Decalcomania'' labels. The costs of the labels and the labor of application make them unattractive for 3-dimensional plastic product application, except for special effects and low-volume production.

Labels similar to the Decalcomania labels but based on a heat transfer system were developed by Dennison Label Co. in the 1950's. Trademarked ''Therimage,'' these labels have found wide application on plastic bottles and other products. In excess of 1 billion labels of this type were used in 1970. Special automatic equipment is required, and label costs are high, but the quality of the finished product has promoted its use in the decorating of high-quality 3-dimensional plastic products. Application is done by the fabricator, contract decorators, and also by packagers.

Scrap Plastic. Printing of plastic film results in 6 to 8 percent SP. Some fabricators and contract printers salvage products by removing the ink and redecorating the product. Few packagers salvage printed bottles rejected at the packaging line. Very recently, independent salvage operations have become commercially available to remove ink and return products for redecorating. These independent systems, however, are practical only for fairly large lots of individual products. Small lots of printed rejects end up as NP.

Labeling plastic products occasionally results in rejects by the packager. If recognized on the production line, paper labels can be removed before the adhesive sets and the bottle is decorated, but Decal and ‘‘Therimage’’ labels cannot. Bottles with paper labels are difficult to reprocess because the paper particles contaminate the product. This results in products with poor appearance and properties. Decal- and Therimage-labeled bottles can be reprocessed, but heavy screen packs on the repelletizers only remove large ink particles; therefore, the resulting pellets only can be used for dark colored formulas. As a result, much of the printed scrap ends up as NP.

The least expensive and lowest NP-producing process of decorating 3-dimensional plastic products is embossing. All other decorating processes result in contamination of the reprocessed plastic with ink or paper particles. An approximate rating of decorating processes in terms of increasing difficulty to reprocess is as follows: (1) embossing; (2) offset printing; (3) silk screen printing; (4) hot stamp printing; (5) decals; (6) paper labels.

Reprocessing

In the broad sense, reprocessing is compounding. Not only are different materials mixed together in this process, but usually contaminants are removed. Reprocessing requires equipment such as Banbury mixers, two-roll mills, extruders, blenders, grinders, choppers, and a variety of specialized equipment. As indicated in the previous section, reprocessing is often an integral part of fabrication. For example, in injection molding, sprues, runners, and rejects are often fed directly into the molding equipment or into granulators that automatically remix and recycle the scrap with virgin resin.

Reprocessing also is carried out by a small segment of the plastics industry--the reprocessor. Reprocessors usually function as compounders and jobbers as well. The reprocessor purchases a wide variety of scrap plastic from resin producers, fabricators, and some converters. If he reprocesses PVC, for example, his raw material may be granulated rigid or flexible PVC with or without contaminants such as dirt or burnt pieces of polymer. He also may accept a shipment of plastic bottles that did not meet specifications, or he might purchase an array of pieces of colored PVC sheet, or large chunks from an extruding operation. Reprocessors who buy polyolefin scrap also purchase strands from the extruder and batches of polyolefin resin that are still wet from the washing step.

Operations and Equipment. The following are examples of operations involved in reprocessing. A chopper or a guillotine is usually used to reduce large chunks into small pieces that can be fed into a granulating machine. The granulating scrap is then blended with other additives, or fed directly to an extruder, where it is pelletized or diced. Film scrap is often made into confetti and similarly fed directly into an extruder.

A common practice is to blend scrap with virgin resin. The reprocessor uses multiple screen packs in the extruder to remove contaminants such as wood, paper, garbage, dirt, and metal. Ferrous metal is sometimes removed by placing magnets on conveyors and/or the hopper filled with scrap. Processing contaminated material through the extruders using a number of screen packs reduces production rates considerably. For example, running virgin material, one can obtain in a given piece of equipment rates of 2,000 pounds per hour, whereas rates as low as 500 pounds per hour are obtained with some of the heavily contaminated scrap plastic.

As a general rule, reprocessing involves blending to obtain a homogeneous product. Usually a number of small lots of scrap are mixed in a blender before being extruded and pelletized. Because the reprocessor deals with a variety of colored scrap or discolored products, he often adds carbon black to the blend and then sells a black secondary resin.

Reprocessors sometimes wash the scrap plastic to remove contaminants. As an example, the chopped material can be spread out and agitated on a large trough and cleaned with hot water. Afterward, the washed material can be dumped into a device where dirt and other contaminants are pulled down, and the plastic skimmed off as a wet slurry. This process is used with polyolefins, which have a density less than one. The plastic-water slurry is then centrifuged and the recovered plastic dried prior to extrusion.

Under certain circumstances, for example, when reprocessing colored sheet scrap, if there is sufficient amount of each color, the reprocessor will accept the scrap from the fabricator or converter and, for a toll charge, reprocess and return it to the original user in a granulated or pelletized form ready for normal processing. Because the fabricator usually must known his raw material, this method of reprocessing a company's scrap is popular.

Reprocessing often involves altering the flow characteristics of the polymer by blending different lots, or adding virgin resin. Other times it may be necessary to process the scrap through the extruder more than once to remove all of the contaminants and/or alter its physical properties.

Problems in Reprocessing. The principal difficulty in recycling or reprocessing plastics is that they are generally not compatible with each other. If a mixture of different plastic types is used to fabricate an end item, the resulting product can appear striated, and it often fibrillates. Not only does a mixture give rise to a product with a poor appearance, but the physical properties of the product also suffer. Nevertheless, some of the major thermoplastics can be mixed to a limited extent, depending on the product desired. For example, low- and high-density polyethylenes are miscible in all proportions but, due to the difference in melting points, difficulties can arise in certain processing. Polypropylene also can be mixed with polyethylenes at levels up to 15 percent without causing serious problems and, similarly, a mixture containing up to 15 percent polyethylenes and the remainder polypropylene is a usable combination. Depending on the concentration of vinyl acetate in the commercial ethylene-vinyl acetate copolymer, these polymers also are partially miscible with polyethylenes.

Polymers vary in their ease of being reprocessed. Polystyrene reprocesses well, but loses some physical properties. Generally, opacity increases with reprocessing, and tinted crystal polystyrene can become opaque. Polystyrene is very sensitive to contamination with other polymers. The polyethylenes, on the other hand, tend to oxidize with each heat cycle and the melt flow decreases. Polypropylene does the opposite. Its melt flow increases as it is subjected to multiple cycles. Oftentimes contamination with other polymers tends to embrittle polypropylene. Furthermore, due to the ease of oxidation of polypropylene, it tends to brown with recycling. PVC, because of its poor heat stability, is recycled with difficulty; however, by adding auxiliary stabilizer PVC can be recycled. ABS resins tend to lose impact as the heat cycles increase, and it also has a tendency to discolor. Light colors are difficult to maintain, and other physical properties are reduced on recycling.

Scrap Plastic Generation. Reprocessing involves considerable losses due to the high state of contamination of the raw material. In some instances the reprocessor has to hand pick his way through the raw material to insure that grossly contaminated products or gross contaminants are removed. Losses in this selection process can easily go up to 10 percent. On extrusion and compounding, the levels of NP generation vary from 1 to 3 percent. Generally, short runs have high losses.

PART II

THE ECONOMICS OF THE PLASTICS INDUSTRY

INDUSTRY STRUCTURE

The plastics industry includes three principal sectors--basic raw materials (e.g., monomers), resins (polymers and compounds), and end products, supported by two smaller business sectors--chemical additives and fabricating equipment. A secondary sector is the reprocessing area which transforms scrap plastic into secondary resins. All of the sectors are involved in making fabricated products (Figure 24).

The cumulative value of shipments of all the products and fabricating equipment made or used by the plastics industry approximated $24 billion in 1970 (Table 11). The production value of resins (also called plastic materials) accounted for about $4 billion of this total (about 20 billion lbs at an average value of nearly 20 cents per lb). Roughly $2 billion worth of petrochemical raw materials were used in the manufacture of polymers for use in plastic products, and about $800 million worth of additives (colorants, stabilizers, etc) were mixed with the polymers to make compounds. When resins and compounds are combined with other materials (e.g., paper and textiles) and processed into semifinished or finished products, the resulting plastic products have a value at the manufacturer's level of over three times the cost of the plastic materials alone: or approximately $17 billion. Approximately $300 to $400 million worth of new fabricating machinery and equipment (injection molding machines, dies, extruders, etc) is sold each year.

Roughly two thirds of all resin is made by companies in the chemical and allied products industry (Standard Industrial Classification Group No. 28) such as du Pont, Dow, and Union Carbide. The other one third is produced by petroleum (e.g., Phillips and Shell), rubber (Goodrich, Uniroyal), and other nonchemical companies (e.g., Borden and Eastman Kodak). Resins account for about 10 percent of the total sales of the broadly-based chemical and allied-products industry and for approximately 20 percent of the total sales of the basic chemicals industry, a further sub division of the larger chemical and allied products industry.

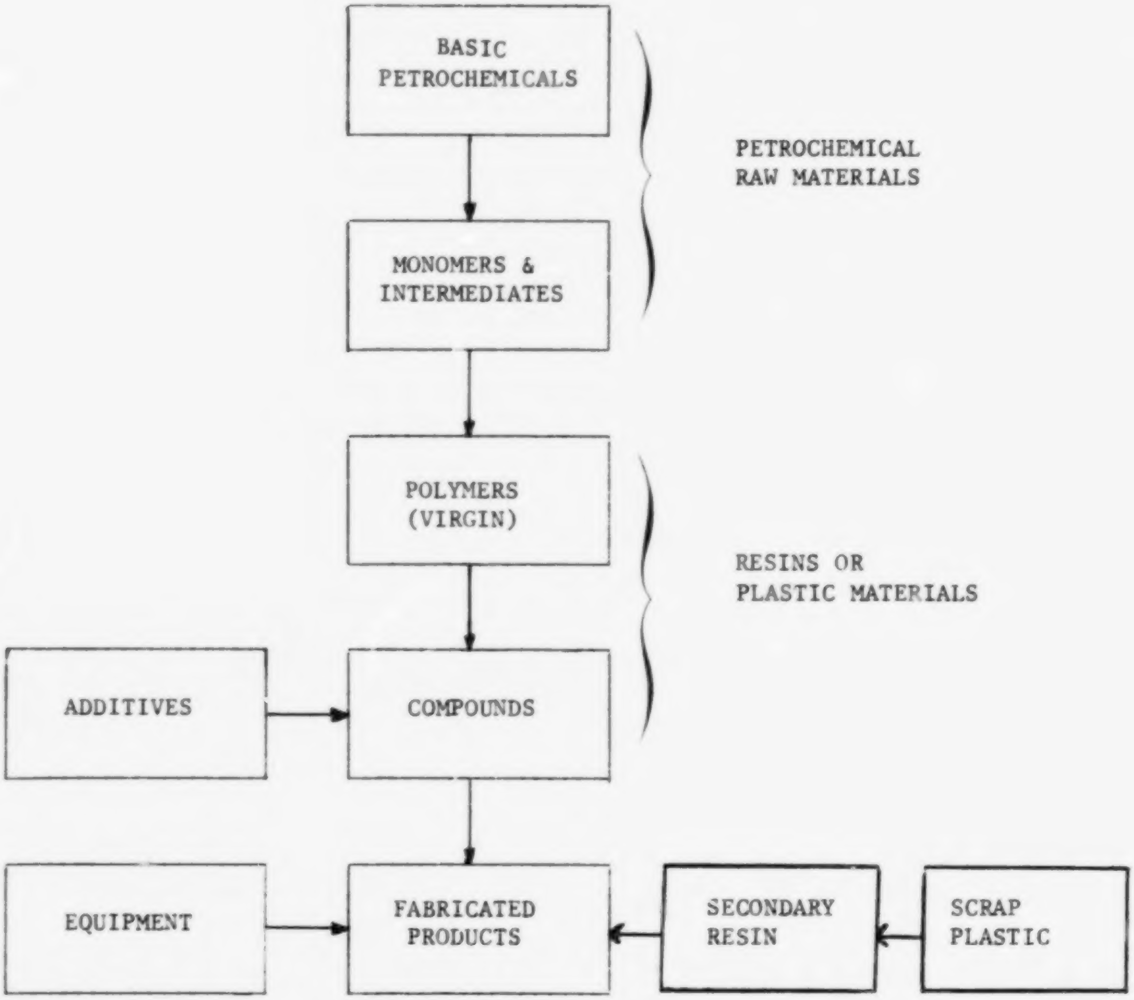

BASIC PETROCHEMICALS
MONOMERS & INTERMEDIATES
PETROCHEMICAL RAW MATERIALS
POLYMERS (VIRGIN)
RESINS OR PLASTIC MATERIALS
ADDITIVES
COMPOUNDS
EQUIPMENT
FABRICATED PRODUCTS
SECONDARY RESIN
SCRAP PLASTIC

Figure 24. Structure of the plastics industry. Both virgin and secondary resins can be used to make fabricated products.

TABLE 11

APPROXIMATE SIZE OF THE PLASTICS INDUSTRY 1970*

Product sector		Production value (billion $)	Remarks
Petrochemical Raw Materials		2	Ethylene, styrene, etc.; produced by large petroleum and chemical companies, most of which also produce resins.
Polymers	Resins	4	10% of basic chemical sales; 20 billion lb; about 250 producers including 30-35 majors.
Chemical Additives		0.8	Plasticizers, stabilizers, fillers, etc.; about 200 producers of all sizes.
Fabricating Equipment		0.3	Molding machines, etc.; over 200 companies, mostly small-to-medium-size independent manufacturers.
Fabricated Products		17	40 billion lb; about equally divided among materials producers, several hundred end product companies, and over 2500 independent processors.
Cumulative Total (rounded)		24	

* Source: Arthur D. Little, Inc.

The U.S. Tariff Commission identified 270 companies as resin producers in 1969, the most recent year of its final listing of companies. This represented a decrease of 18 companies compared with 1968. About 30 to 35 of these producers account for most of the output of the plastic materials. Nearly all resin producers are integrated forward to fabricated products to some degree, and approximately 30 to 35 percent of all resin is captively fabricated by end-product companies (the manufacturer/packager segment, such as the automotive or appliance manufacturers); these companies use most of the fabricated products captively.

The other 35 to 45 percent of all resin is processed by over 2,500 independent fabricators, most of which are small privately-owned businesses (under 20 employees) that specialize in the custom processing (e.g., molding) of plastics for larger end-product firms. These companies may buy polymers and additives and mix their own compounds or buy already prepared compounds; in either case, they transform plastic materials into various shaped articles or into thin film. This independent fabricator sector continues to consolidate, as more of the resin producers and end-product companies do relatively more fabricating. For several year, materials producers and end-product companies have been acquiring many of the more progressive independent fabricators, and we expect this trend to continue, particularly by the end-product producers. However, because of the continuing dynamic nature of the plastics industry and the need for fabrication to be done near the centers of population, the number of small independent fabricators will probably remain above 2,500 through 1975.

There are also over 3000 converters. These firms purchase films and other semi-finished plastics items and perform such operations as printing, coating, etc (see Part I). About 25 companies produce most of the additives used to make compounds. These tend to be the smaller chemical companies (e.g., Emery Industries and Wetco Chemical) which are not large resin producers.

Over 200 small-to-medium-size firms (e.g., USM, Cincinnati Milacron, Crompton & Knowles, Koehring, and Midland Ross) manufacture the processing equipment (e.g., molding machines, extruders, dies, calenders, coating equipment) used by plastics fabricators. With a few exceptions, these firms do not produce resins or additivies, but some do fabricate selected plastic products.

The secondary reprocessor segment of the plastics industry is composed of 50 to 75 companies, most of which are small. Sales of secondary resins (mainly compound) by this segment were about one billion pounds valued at about $150 million in 1970 (about 4 to 5 percent of the output and value of the primary resin industry. Over the past decade the amount of resin handled by the reprocessor has been decreasing as a percent of total resin production. As the basic resin producers, who provide most of the scrap plastic, became more cost conscious (as their profit margins continued to decrease during the 1960's), they also became more efficient and generated less scrap. This effect reduced the volume of SP going through the reprocessor channels. Moreover, as virgin resin prices dropped, the narrowing of the selling price gap between virgin off-grade and secondary resin reduced the economic incentive for the reprocessing or recycling of scrap plastic by the reprocessor. Thus, with the decreased profitability of reprocessing, reprocessors have turned to other operations such as the compounding and distributing of virgin resins, especially the off-grade material. In 1950, reprocessor companies often derived all of their income from reprocessing; today it typically represents only 25 to 30 percent of their total business.

GROWTH AND PRICE TRENDS

Resins

The production value (production value, as used in this report, is calculated by multiplying the total production of a material, in pounds, by the average selling price, as reported by the U.S. Tariff Commission or as estimated by us) of resins in current dollars increased at an average annual rate of nearly 7 percent over the past 5 years from $2.9 billion in 1965 to about $4 billion in 1970 (Figure 25). The value had also increased at about 7 percent annually on average over the preceding five-year period. For the first time since 1965, average prices of resins in 1969 and 1970 remained relatively stable, dropping only about 5 percent in total since 1968. The average price of resin decreased from about 31 cents per lb in 1960 to an estimated 20 cents per lb in 1970, a drop of 11 cents or about 36 percent in the ten years (Figure 25). From 1960 through 1968 the price trend had been steadily downward, except in 1963 and 1965. The average price decreased 6 cents per lb (or 19 percent) in the five years, 1960 to 1965, and another 5 cents per lb (20 percent) in the three years, 1965 to 1968. Since then, it has been relatively stable. Because of the widespread drop-off in the U.S. economy in 1970, we estimate that growth in the production of resins was only about 7 percent in 1970, to about 20 billion pounds. Production value grew to about $4 billion or by 6 percent. This compares with the historical (15 years) average growth on values for resin of about 8 percent per year.

We expect an average price decline of about 5 percent in total (about 1 cent per lb) over the next four years. The price decreases will take place in the specialty types and grades of resins rather than in the low-priced, high-volume commodity grades, which likely will, in fact, show a slight increase in average price by 1975. We expect that the average price of resin has remained essentially stable this year (1970). However, we anticipate a small increase in 1972 (e.g., 2 to 3 percent), then a

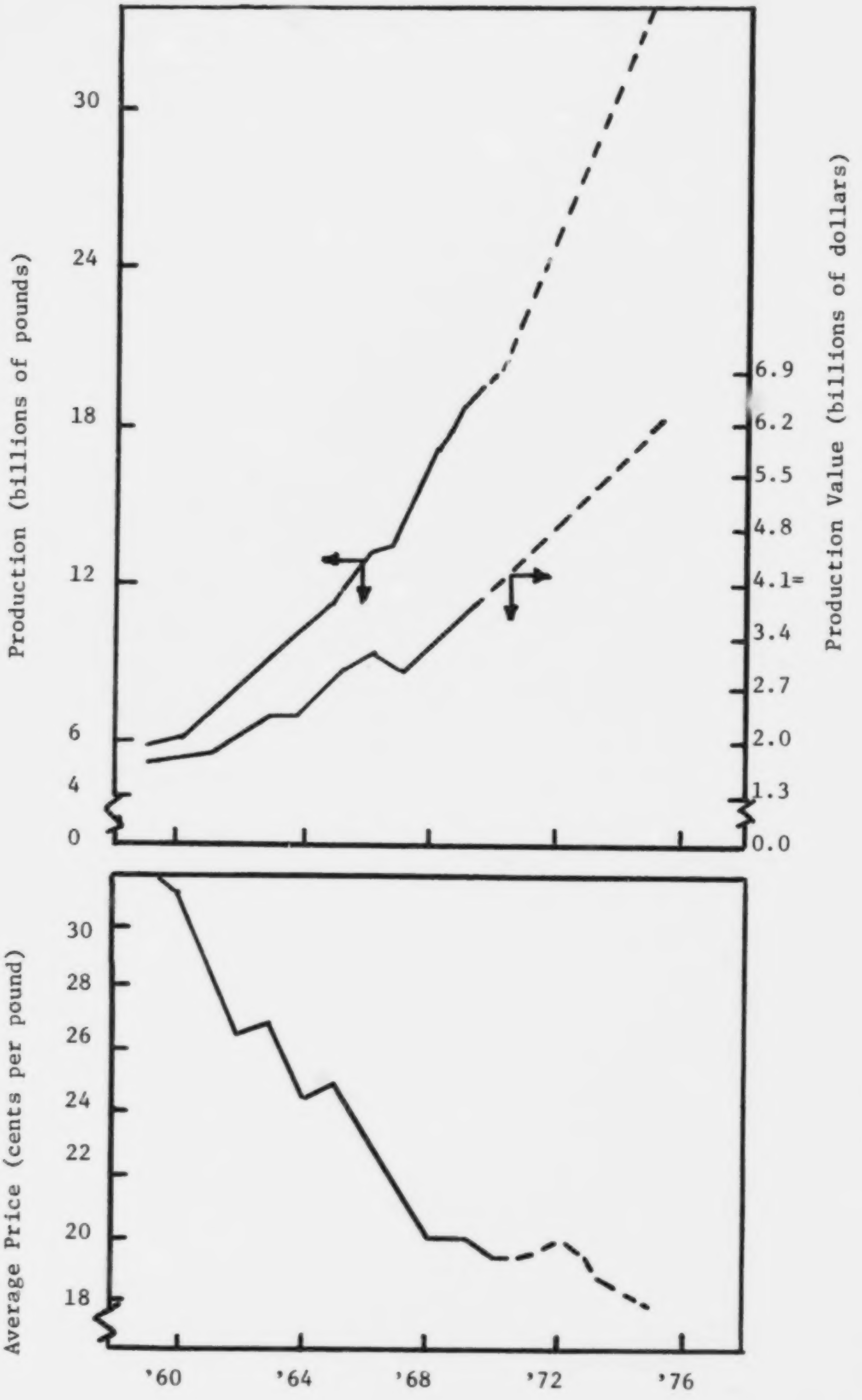


Figure 25. The production value of resins has increased at an average annual rate of 7 percent from 1965 to 1970, while the average price decreased about 11 cents.

small decline from 1973 to 1975, reaching an average of 18 cents per lb in 1975.

On the assumption that the general economy will begin to accelerate soon and that real GNP growth will average 4 to 4.5 percent annually over the next few years, we project that resin production will grow at about 12 percent per year in volume and about 10 percent per year in value in the 1970 to 1975 period. This compares with a growth of about 11 percent per year in volume and 7 percent per year in value during the past five year period (1965 to 1970). We estimate, therefore, that total production of all resin will be approximately 35 billion pounds in 1975, and the production value will approximate $6.3 billion in that year.

Off-grade virgin resin, which accounts for approximately 10 percent of basic resin production (about 2 billion pounds) typically sells at a price about 10 percent below the lowest price for the prime (or specification grade) resin. Thus, the off-grade resin price historically ''followed'' that of the prime product. However, while the price of virgin resin has been dropping substantially, the lowering of the price of secondary resin has been limited to a greater extent by the rising costs of labor and distribution involved in reprocessing, which are relatively higher than those for virgin resin production. Secondary resin competes mainly with off-grade virgin resin. In 1961, for example, the price of secondary LDPE material was about 3 cents per lb less than an equivalent off-grade resin. Today, the difference is only about 1 cent per lb or less.

Plastic Products

The growth rate in the sales of fabricated plastic products can be determined to a reasonable degree on examination of the data reported by the U.S. Department of Commerce.[2] An examination of this information shows that during the ten years 1960 to 1970, the average annual growth in the value of factory shipments (sales) of this industry sector was nearly 13 percent. During the most recent 5-year period (1965 to 1970), the average rate of growth was about the same. Estimated sales of the 2,500 or so independent plastic fabricators which make up S.I.C. 3079 were over $7.7 billion in 1970 according to the Department of Commerce. These sales do not include the value of fabricated plastic products made by companies whose basic S.I.C. categories are other than 3079. We estimate that roughly $9 billion worth of plastic products were fabricated in 1970 by companies that are basic resin producers (e.g., chemical, petroleum and rubber companies) and end product companies. Thus, the total value of all fabricated plastic products was about $17 billion in 1970.

The average selling prices of plastic products taken as a whole have followed the general upward price curve of most industrial and consumer products. For example, in the ten years ending 1968, prices (current dollar basis) were up about 9 percent in total. However, in 1969 alone, prices for these types of products increased about 4 percent to 113 on the price index (1957 to 1959 = 100) and they are currently at a level of about 118. This is in sharp contrast to the selling price index of the basic resins, which is now at a level of about 83.

MARKETS

In 1970, the broad industry category of building and construction consumed about one-quarter (by weight) and packaging about 20 percent of all plastic materials (Table 12). When exports of resins are excluded (about 8 percent by weight of all resin produced), these two industry groups accounted for about 26 percent and 22 percent, respectively, of total domestic plastic materials use in 1970. We expect each of these major end-use markets to consume an even larger share of plastics production in 1975 (28 percent and 23 percent, respectively, of domestic consumption). Furniture will represent the fastest growing outlet for plastics over the next five years (19 percent per year), followed by transportation equipment (16 percent), and building construction (14 percent). Markets growing at about the industry average of 12 percent per year include: packaging, appliances and toys. Slower growing markets will be housewares, exports, and the very broad category of all other domestic uses.

Building and Construction

We estimate that building and construction products of all types consumed approximately 4.7 billion pounds of resins last year. Plastics now account for about 5 percent by weight of the average single family housing unit. Applications include protective coatings (paints), wire and cable insulation, floor and wall coverings, adhesives and caulking and sealing compounds, pipe, electrical conduit, wall panels and other surfacing materials, decorative laminates, lighting fixtures, foamed insulation products, glazing and siding, shutters, window frames, downspouts and gutters, vapor barriers, bathroom components and other uses.

We expect the growth of resins for building and construction applications to reach a consumption level of 9.1 billion pounds in 1975. The high demand for residential housing, the trend toward the greater production of modular units, and the growing demand for ‘‘mobile’’ homes will all contribute to this strong growth. Other contributing factors will be the increasing acceptance of plastic pipe by local building codes, which is resulting in a growth in plastics consumption of 20 to 25 percent per year for pipe manufacture, and increased use of vinyl siding and other

TABLE 12

USE OF RESINS BY MARKET, 1970-1975*

Market	1970 (billion lb)	1970 (%)	1975 (billion lb)	1975 (%)	Average growth (%/year)	Major types
Building and construction	4.7	24	9.1	26	14	PVC, phenolic, alkyd, urea, polyester, LDPE, styrenes, acrylics
Packaging	4.0	20	6.7	19	11	LDPE, HDPE, styrenes, PVC, polypropylene
Transportation equipment (mainly automotive)	1.1	6	2.4	7	16	PVC, polypropylene, urethane, polyester, ABS
Housewares	1.0	5	1.4	4	7	LDPE, HDPE, styrenes, PVC
Furniture	0.7	4	1.7	5	19	PVC, styrenes, urethane
Appliances	0.6	3	1.0	3	11	Styrenes, phenolic, polypropylene, urethane
Toys, dolls and games	0.6	3	1.0	3	12	Styrenes, LDPE, HDPE, PVC
All other domestic uses †	5.7	28	9.2	27	10	All types
Exports	1.6	8	2.5	7	9	PVC, LDPE, HDPE, polypropylene
Total	20.0	100	35.0	100	12	

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* Source: Modern Plastics, 48(1), Jan. 1971; and Arthur D. Little, Inc., estimates.

† Includes agriculture, apparel, and accessories, business machines, electrical and electronic products, footwear, hardware, health care, other household products, instruments and controls, jewelry, luggage, musical instruments, novelties, optical products, paint, pens and pencils, photographic products, records and tapes, and sporting goods.

rigid plastic building components such as glass-reinforced plastic bathroom tubs, showers, and fixtures.

Even if the amount of plastics used in the average home does not increase substantially, the latent demand for residential housing is such that the annual number of housing starts could possibly double in 1975 compared to 1970. We believe, however, that plastics will continue to replace traditional building materials in residential as well as commercial, institutional, and industrial construction. For example, Dow Chemical has built an experimental home which contains about 50 percent by weight of plastic. Monsanto, DuPont, Hercules, Allied Chemical, American Cyanamid, Olin, and others are also increasing their corporate efforts in the building and construction area and can be expected to develop new products and complete systems which will use large amounts of resins. The Department of Housing and Urban Development's ''Operational Breakthrough'' Program, aimed at stimulating the development of new technologies for housing construction, includes several plastic-based building concepts.

Packaging

Packaging uses in 1970 consumed about 4 billion pounds of resin, principally the polyethylenes, styrene polymers, polypropylene, and PVC. Plastic packaging products included about 1.8 billion pounds of plastic film and sheet (about two thirds of which was polyethylene), 700 million pounds of bottles, 700 million pounds of molded containers and lids (including foamed cups and trays), 600 million pounds of coatings (e.g., for paper, metals and plastic films), and 100 million pounds of closures.

Plastics now account for about 10 percent of the value of all packaging materials, up from about 7 percent five years ago. We expect plastic packaging materials to grow at over twice the growth rate of the entire packaging materials business, which we expect will continue at about 6 percent annually. Annual growth of plastics in packaging was about 15 percent per year from 1965 to 1970 (on a weight basis) and should average about 11 percent per year through 1975 (to about 6.7 billion lbs). If the Food and Drug Administration approves the broader use of plastics for food containers in the next year or two and plastics really begin to penetrate the carbonated beverage market, the growth of plastics in packaging could exceed this projection. The continuing customer preference for convenience--in the form of nonreturnable containers, lighter-weight packages, and greater product protection--and the improving economics relative to the other competitive materials are the major forces behind the increasing relative use of plastics in packaging.

Rigid Containers. Plastic bottles continue to represent the fastest growing segment of the plastics packaging market. The number of plastic bottles produced has increased from 1 billion units to over 5 billion units in the last ten years, a growth rate of about 18 percent per year. Value of shipments of plastic bottles of $300 million in 1969 represented only about 5 percent of the value of the combined shipments of metal cans ($3.9 billion) and glass bottles ($1.9 billion). We anticipate that the consumption of plastic for bottles will at least double by 1975, a growth rate of 15 percent per year.

The very large potential for plastic bottles is for food products including beverages. Today plastic represents only about 1 percent of a 90-billion-unit food-container market. However, the plastic carbonated beverage container is now ''on the horizon'' and is being touted because it is lightweight and safe. The two candidate materials for this application are Barex (Standard Oil of Ohio) and Lopac (Monsanto)--both are clear, high-barrier resins. Barex is reportedly a copolymer of acrylonitrile and an acrylate ester (probably ethyl acrylate) which also contains a rubber based impact modifier, and Lopac is said to be a copolymer of methacrylonitrile and styrene. Both resins are relatively expensive--about 50 cents per lb today. However, these are developmental prices and they should become available for 35 to 40 cents per lb as production volume is increased substantially. Today these resins are being produced in facilities having a capacity of only 10 to 12 million pounds per year, which are small resin plants by today's standards.

Pepsico ran a market test of bottles made of Barex in the Las Vegas area in early 1970, and Coca-Cola has been testing Lopac bottles in New Bedford, Massachusetts, and Providence, Rhode Island for several months. In general, the reception to both types of bottles has been excellent, although some have voiced a concern about the effect of these containers on the environment.

The rate and degree of penetration of the market by the plastic beverage container will be affected not only by the price and availability of the resin but also by the availability of appropriate high-speed fabrication equipment for use in the bottler's facilities. To compete with the 10 oz. one-way glass container that now sells for 3.3 to 3.8 cents, the weight of the equivalent plastic container should be no more than 1/15 lb. At present most of the 10 oz. plastic containers weigh about 1/10 lb. The total cost of fabrication, including amortization of the investment, and pretax profit should be about 1 cent per plastic bottle. These economic requirements cannot be fully met today, and therefore it is likely that the soft-drink bottling market will not represent a major new outlet for plastics until 1975, or soon thereafter. But by 1980, as much as 2 billion pounds of plastic could be used in this field, which would represent about half of the 60 billion fills estimated for that time. This assumes all of the economic requirements would be met, and that the public accepts this type of container.

The plastic milk bottle will be another major growth area for plastics, especially HDPE, in the next several years. Plastic-coated (LDPE) paperboard cartons still represent about 70 percent of the 27 billion quarts of milk packaged annually. Plastic containers, as such, now account for only about 5 percent of fluid milk packaging (up from about 3 percent in 1967). We expect that consumption of HDPE used for rigid milk containers will increase from about 140 million pounds in 1970 to 450 million pounds by 1975 and perhaps to 800 million pounds by 1980.

Plastics should also continue to capture a larger share of the rest of the rigid container market. Plastic baskets, boxes, trays, jars, tubs, cups, tumblers, and closures taken together increased in value of shipments from about $400 million in 1965 to an estimated $800 million in 1970, a growth rate of 15 percent per year in value. We expect this growth rate to decrease only slightly through 1975.

Flexible Packaging. Flexible plastic products (e.g., bags and films) will also increase their share of the food packaging market, especially in coated products and laminations of thin film with paper and metal foil. Trash bags, a non-existent market only a few years ago, are widely used today. However, we expect this market for polyethylene to growth from about 200 million pounds in 1970 to perhaps 800 million pounds in 1975 or to about 65 percent of the total current use of all polyethylene film for packaging.

Another flexible plastic product on the horizon today that could perhaps become significant is the plastic milk pouch. These containers have been in use in Europe for some years. They now have a ''foothold'' in Canada (accounting for 20 to 30 percent of the milk packaging market) and have now entered the U.S. dairy industry as well. Approximately 40 installations are in the U.S.

The pouches are essentially hermetically sealed bags of special formula LDPE film holding 1 quart or 1/2 gallon. They are multi-packed in polyethylene outer bags. The consumer places the pouch in a rigid plastic pitcher (generally molded out of polyethylene), slits only a corner of the bag and is ready to pour.

The milk-filled pouch requires less space in the refrigerator, and when inserted into the pitcher is easy to handle and pour; but most importantly, this container minimizes the solid waste problem inasmuch as the empty bag is easily compressed and uses a minimum weight of plastic as compared with the all-plastic bottle. Reputedly, there are less leaks in the bagged milk then in the plastic-coated paper milk cartons.

One of the important advantages of the pouch is its lower cost. The cost of materials per gallon of milk in two one-half gallon bags, including the outer bag, is between 3.3 and 4 cents per gallon, compared to about 5.2 cents per gallon for two one-half gallon paperboard cartons. The saving of space at the dairy for the packaging material inventory is another factor.

Although milk is the immediate goal of the pouch, other potential products are: motor oil, windshield wiper fluid, juices, water, hand lotion, etc. The extent to which the pouch will be able to capture some of the fluid milk packaging market is impossible to estimate at the present time. Some say that the pouch will be able to capture 20 to 25 percent of the U.S. market within the next few years. Others are much more pessimistic and believe that the U.S. housewife who is keenly interested in convenience will not find this package suitable.

Shrinkable packaging films, plastic shipping bags, grocery bags, and large bags for department store use are also likely strong growth areas for flexible plastic packaging by 1975. Including the value of converted products, flexible plastic packaging sales totaled about $2 billion in 1970 (including cellophane) and represented about 2.4 billion pounds of resin. We expect this to grow to about 3.7 billion pounds of resin by 1975, or about 9 percent per year.

Transportation

Transportation equipment of all types consumed an estimated 1.1 billion pounds of resins in 1970. This amounts to about 6 percent of total domestic use of these basic materials. We project an average growth in this market of about 16 percent per year (to 2.4 billion lbs) through 1975. About three quarters of all the plastics consumption by the transportation equipment industry (or over 800 million pounds in 1970) is used in passenger-car production. The average 1971 model gear American-made passenger car contains over 100 pounds of plastics, a 15 percent per year increase in the average per-car use over the past 10 years. This current level of use in the typical automobile almost equals that of rubber (excluding the tires) and of die-cast zinc, and has surpassed that of aluminum (which is about 80 lbs per car). Plastics applications are also growing rapidly in other forms of transportation equipment, including trucks, buses, and off-the-road vehicles such as recreational types, boats, subway and railroad cars, and aircraft.

The major automotive uses for plastics are upholstery, headliners, molded components (e.g., for heater housings, trunk lids, fender extensions, dashboards and instrument cluster assemblies, and steering wheels) door panel coverings, crash pads, and extruded items such as interior trim. Newer applications for plastics include grilles (both painted and chrome-plated), fender aprons, and gasoline tanks. The automobile manufacturers fabricate investments which provide additional incentive for them to use more plastic per car.

The continuing demand for greater automotive safety has increased the potential for plastics, because of the flexibility they allow in designing safe yet attractive components. A major ''breakthrough'' in the fire resistance of plastics would further increase our estimates of plastics use by the transportation industries. We do not anticipate such a ''breakthrough'' by 1975, however, although we do expect continued improvements in the heat and fire resistance of plastics.

The transportation equipment producers tend to consume higher-priced resins because most applications have very demanding property requirements and engineering specifications. Among the important types of materials used are ABS, glass-reinforced polyester, phenolics, polyurethanes, the higher-price grades of polypropylene, and the engineering thermoplastics such as nylon and acetal.

Other Markets

Housewares. This market was one of the first consumer product areas to use large amounts of plastic. Such familiar items as water pitchers, mixing bowls, refrigerator containers, and waste baskets have long been made of plastic. This market, which consumed about 1 billion pounds of resin in 1970, is fairly well saturated and we expect the future growth rate will be only about 7 percent per year (to 1.4 billion lbs in 1975). The lowest-priced commodity-grade resins are generally used in this market.

Furniture

This represents the fastest growing market for plastics; annual growth is projected at 19 percent from about 700 million pounds in 1970 (4 percent of the market) to 1.7 billion pounds in 1975. The major types of plastics now used are PVC for coated fabrics and urethanes for cushioning. The greatest increase in use will be in the styrene plastics (including ABS) for structural components, PVC films (used for printed veneers), polypropylene moldings, and polyesters (including castings). Currently, plastics (including protective coatings) account for about 20 percent of the value of the raw materials used in furniture manufacture; in five years this will increase to about 30 percent. Plastics permit furniture manufacturers to establish new designs, shapes, and textures to a greater degree than with wood, metal, glass, or textiles. In addition, by using plastics, furniture manufacturers can reduce the number of labor intensive fabrication steps, including assembly, in making the final piece. Further, acquisitions of furniture companies by process industry companies (e.g., by other companies in addition to Armstrong Cork, DeSoto, and U.S. Plywood-Champion Paper) can be expected to increase the greater relative use of plastics in furniture manufacture. We expect this acquisition trend to continue.

Appliances and Toys. The appliance (both major and small) and the toy, doll, and game industries have been important markets for plastics for several years. Each accounted for an estimated 600 million pounds of resin consumption in 1970. These markets are not yet fully saturated and we believe that plastics will continue to penetrate them. We project growth at about 11 to 12 percent per year in each of these two important end-use markets, resulting in consumption of roughly 1 billion pounds of plastics by each in 1975.

All Other Domestic Applications. These applications combined consumed an estimated 30 percent of all plastic materials fabricated in the U.S. in 1970 (about 5.7 billion lbs). These markets include agricultural products (e.g., plastic pipe and protective films); apparel and related products; housings and component parts for computers, business and copying machines, and office equipment; miscellaneous electrical and electronic products; footwear; hardware; health care products (including a variety of plastic items used in hospitals); household products other than housewares (e.g., garden hose, shower curtains, and table covers); luggage; photographic products; phonograph records and stereo tapes; and sporting goods. Because several of these applications are already highly saturated in terms of plastics use, we expect these combined markets to decrease slightly in relative importance, but consumption of resin should still grow by about 10 percent annually to approximately 9.2 billion lbs in 1975.

Exports. From 7 to 10 percent by weight of the total U.S. resin production has been exported annually for the last several years, and about 8 percent in 1970. However, exports have accounted for 9 to 13 percent by value because of the foreign demand for the higher valued specialty grades not yet manufactured by many countries. Exports are expected to decrease to about a 7 percent market share, rising from 1.6 billion pounds in 1969 to 2.5 billion pounds in 1975 (a growth rate of about 9 percent per year). For several years, the export value of plastics and resins has held at about six times the import value, and we expect this approximate ratio to continue for the next few years.

MAJOR THERMOPLASTIC RESINS

Over two dozen different chemical types of resin are commercially important. However, in 1970 all types of polyethylene taken together accounted for about 19 percent of the total production value of all resin and 30 percent by weight; the styrene polymers for 16 percent of the value and 17 percent by weight; and polyvinylchloride, for 11 percent of the value and 16 percent of the total weight (Table 13). These three major families of thermoplastic resin, therefore, represent nearly half the total value of all plastic materials and for about 63 percent of the total

TABLE 13

APPROXIMATE PRODUCTION AND VALUE OF RESINS BY TYPE
1970-1975*

	1970 Production				
Type	Value (MM$)	% of Total Value	Average price (¢/lb., dlvd.)	Billion Lb.	1975 Production (billion lb)
Polyethylene	770	19	13	6.0	11.2
Low density	515	13	12	4.3	7.6
High density	255	7	15	1.7	3.6
Styrenes	615	16	18	3.4	6.0
Polystyrene†	450	12	16	2.8	4.8
ABS	165	4	27	0.6	1.2
Polyvinyl Chloride	450	11	14	3.2	5.2
Phenolic	230	6	22	1.1	1.6
Polypropylene	210	5	21	1.0	2.5
Methacrylate	220	6	55	0.4	0.7
Polyester	170	4	28	0.6	1.3
Alkyd	155	4	26	0.6	0.7
Cellulosic	115	3	60	0.20	0.24
Urea	100	3	20	0.5	0.8
Polyvinyl Acetate	100	3	25	0.4	0.6
Epoxy	75	2	50	0.2	0.3
Polyamide (nylon)	80	2	80	0.1	0.015
Fluorocarbon	75	2	350	0.02	0.03
Melamine	60	2	30	0.2	0.3
All other‡	280	12	22	2.08	3.33
TOTAL	4000	100	20	20	35

* Source: U.S. Tariff Commission; Modern Plastics, 48(1), Jan. 1971 and Arthur D. Little, Inc., estimates

† Includes copolymers

‡ Includes other vinyls (e.g., saran, polyvinyl butyral, polyvinyl alcohol), acrylates, urethane resins, polycarbonates, silicones, acetals, coumarone-indene, and others; values calculated by subtraction.

weight. Other types that accounted for at least 5 percent of total production value in 1970 were the phenolics (the oldest completely synthetic plastic material and the largest of the thermoset resin), polypropylene, and the methacrylates. The fastest growing resin over the next five years will be polypropylene (at 20 percent per year on a weight basis). Others growing faster than the 12-percent-per-year industry average will be the polyethylenes, ABS, and polyesters (largely used in producing glass reinforced structural plastics). Certain specialized materials such as polyurethanes, polycarbonates, and acetals will also exceed the average. Types that will grow at about the industry average include polystyrene, methacrylate, and the epoxies, with PVC growing at somewhat less than this. Growth for the other major types will range from only about 2 percent per year for alkyds to about 4 percent for the celluloses and about 10 percent per year for nylon and fluorocarbon plastics.

Polyethylene

In 1970 the combined output of all types of polyethylene was approximately 6 billion pounds, valued at $770 million. (This weight is about equal to the total production of all resins as recently as ten years ago.) Over 70 percent of the polyethylene currently produced is the low-density type; the balance is high-density material. During 1965 to 1970, production of polyethylene grew at an average of 15 percent per year by weight, with low density increasing 14 percent annually and high density, 17 percent. We estimate that the overall production of polyethylene will grow at 13 percent per year to 11.2 billion pounds in 1975; about two thirds will then be low density and one third high density. By 1980 production could reach 20 billion pounds. Over the 1965 to 1970 period, the average selling price decreased 24 percent for polyethylene so that production value growth was only about 8 percent per year. Average prices for LDPE decreased from about 17 cents per pound in 1965 to 12 cents per pound in 1969 and 1970 (a decrease of 29 percent) and for HDPE, from 19 cents per pound to 15 cents per pound (a 16 percent decrease). We expect the average price of LDPE to hold at the current level or increase slightly through 1975 and the HDPE price to decrease by about 10 percent.

Packaging uses of all types (both flexible and rigid) account for approximately half (by weight) of the total demand for all polyethylene. About 37 percent of the low-density polyethylene is converted into flexible film used for packaging, including the manufacture of trash bags (Table 14). Another 10 percent of the demand for LDPE is for extrusion coating of paper and paperboard for such products as multiwall bags and milk cartons. Two thirds of all high-density polyethylene is used in molded products, and over half of that is blow molded to produce bottles and other rigid containers. The major potential growth for polyethylene will continue to be in packaging. As stated previously, by 1975 large quantities of low-density polyethylene will be used in grocery bags, a new market for

TABLE 14

POLYETHYLENE MARKETS 1970*
(% of Total Demand, By Weight)

End use	Low density	High density	Total polyethylene
Packaging	52	41	49
Flexible (eg. bags, coated paper)	47	5	35
Rigid (eg. bottles, lids, closures)	5	36	14
Building and construction	14	8	12
Wire and cable	10	2	8
Pipe and conduit	2	6	3
Vapor barrier	2	small	1
Housewares	7	12	8
Toys, dolls and games	3	4	3
All other domestic uses	15	23	18
Export	9	12	10
Totals	100	100	100
Production (billion lbs.)	4.3	1.7	6.0

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* Source: Modern Plastics, 48(1), Jan. 1971 and Arthur D. Little, Inc., estimates.

† Includes: Agriculture, transportation equipment, furniture, appliances, sporting goods, other.

polyethylene. We also believe that the refuse and trash-bag market will continue to grow rapidly, as mentioned above. High-density polyethylene sales should benefit from the expected growth in plastic milk bottle and oil can uses as well as growth in the use of other rigid bottles and containers particularly for other food products.

Union Carbide is the largest producer of both types of polyethylene, and DuPont and Dow Chemical are also major producers of both types. Gulf Oil, Dart Industries (in conjunction with El Paso Natural Gas), Eastman Kodak and Northern Natural Gas are significant producers of low-density polyethylene, and Allied Chemical, Celanese, Phillips Petroleum, and Monsanto produce major quantities of high-density polyethylene.

Styrene Plastics

From 1965 to 1970 production growth rate of all styrene resins taken together averaged about 11 percent per year. During most of this period the price of styrene plastics held much firmer than that of the polyethylenes. For example, in 1965 the average price of all styrene based resins was about 21 cents per pound and the price held at the 20 to 21 cents per pound level through 1968. In 1969 and 1970 it was about 18 cents per pound, which represented a five-year decline of only 14 percent. The 1970 production value of all styrene resins was about $615 million, nearly three quarters of which ($450 million) was accounted for by styrene homopolymer and copolymer resins of all types (including impact grades), and the remaining one quarter ($165 million) mainly by ABS. In the next five years, we expect average growth rates of about 12 percent per year for the styrene-type resins, and about 15 percent per year for the ABS products. We estimate that production of all styrene resins will grow from 3.4 million pounds in 1970 to approximately 6 billion pounds by 1975, and perhaps 10 billion pounds by 1980. We expect the average price of polystyrene to decrease by about 10 percent during the next five years (mainly because of decreases in the higher priced impact grades and in expandable beads). The average ABS price, which is about 27 cents per pound now, will decrease somewhat more than 10 percent in the next five years.

As is the case with polyethylene, packaging is also the largest single end-use outlet for polystyrene, accounting for about 22 percent of the total market (Table 15). Foamed packaging products is one of the fastest growing segments of the polystyrene market. Toys, housewares, and appliance parts are other major end-use applications for polystyrene. Principal markets for ABS include appliances and automotive parts, pipe, components for business machines, telephone housings, and luggage.

Of the 20 or so producers of polystyrene, Dow, Monsanto, Sinclair-Koppers, Foster Grant, and American Petrofina (Cosden) are the largest producers. New producers include U.S. Steel and Polymer Corp. of Canada. Only six

TABLE 15

STYRENE PLASTICS MARKETS 1970*
(% of Total Demand, by Weight)

Styrene resins	
Packaging	22
Textile and paper coating	12
Toys	9
Housewares	8
Appliances	7
Export	4
All other domestic uses †	38
Total	100
Production (billion lb.)	2.8
ABS	
Appliances	17
Automotive	16
Pipe	12
Business machines, telephones	9
Luggage	6
Export	9
All other domestic uses ‡	
Total	100
Production (billion lb.)	0.6

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* Source: Modern Plastics, 48(1), Jan. 1971 and Arthur D. Little, Inc., estimates.

† Includes paints, adhesives, insulation, pipe, furniture, novelties, and fixtures.

‡ Includes sporting goods, shoe heels, furniture.

companies produce ABS. They are Borg-Warner (Marbon Division), Uniroyal, Monsanto, Dow, Dart Industries and B. F. Goodrich.

Polyvinyl Chloride (PVC)

In 1970, PVC (including copolymers) accounted for about 11 percent of the production value of all resins, grossing about $450 million in sales. During the past five years, growth in production of PVC has averaged 12 percent per year; we expect a slight decrease to about 11 percent per year through 1975. Production of PVC resin will grow from 3.2 billion pounds in 1970 to 5.2 billion pounds in 1975, and perhaps to over 8 billion pounds by 1980. The average price of PVC decreased by about 20 percent over the 1965 to 1970 period and is expected to drop another 5 percent by 1975, mainly because of a drop in the higher priced paste-grade and rigid-grade materials.

The broad category of building and construction is the largest end-use market for PVC; it represents 40 percent of the total market (Table 16). This category includes flooring, electrical products, mainly wire and cable coatings, pipe and conduit, and siding. A large variety of home products such as furniture upholstery, table covers, shower curtains, garden hose, and wall covering, when taken together account for 19 percent of the PVC market. Other primary end-use applications include products for the automotive and other transportation equipment fields (e.g., vehicles, boats, and aircraft), flexible film and rigid bottles for packaging, phonograph records, footwear, protective coating, apparel, and toys. We expect the most rapid growth for the vinyls to be in the building and construction industries (for pipe, conduit, siding, and rainwater goods), and in the packaging industry, particularly for flexible film and, to a lesser extent, for bottles. There are about two dozen producers of PVC resin including B. F. Goodrich, the industry leader, Union Carbide, Borden, Firestone, Diamond Shamrock, and Tenneco.

Polypropylene

Polypropylene has been the fastest growing major plastic for several years; in 1970 it accounted for about 5 percent of total production value, or $230 million in sales. Polypropylene will continue to be the most rapidly growing plastic, and we estimate average growth at about 20 percent per year by weight and about 18 percent per year by value in the 1970 to 1975 period. On this basis, polypropylene production will approximate 2.5 billion pounds in 1975, and it will displace phenolics as the fifth largest individual type of resin by that time. Between 1965 and 1970 the average price of polypropylene stabilized at the 21 to 22 cents per pound level compared to its drastic previous five-year decline, when it dropped from about 40 cents per pound in 1960 to 22 cents per pound in 1965. We expect the average price of polypropylene to decrease by about 10 percent in total during the next five years to about 20 cents per pound.

TABLE 16

POLYVINYL CHLORIDE MARKETS 1970*
(% of Total Demand, by Weight)

Building and construction (flooring, wire & cable, pipe)	40
Home products	19
Transportation equipment	7
Packaging	5
Phonograph records	5
Export	7
All other uses[†]	17
Total	100
Production (billion lb.)	3.2

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* Source: Modern Plastics, 48(1), Jan. 1971 and Arthur D. Little, Inc., estimates.

[†] Includes footwear, protective coatings, apparel, dolls.

Over half of the domestic market for polypropylene is in a wide variety of molded products, including automotive parts, housewares, and toys (Table 17). Unlike all of the other major thermoplastics, textile fibers and monofilaments account for about 30 percent of total U.S. polypropylene use; packaging represents 18 percent of U.S. consumption, of which half is flexible film and half molded products such as closures. We expect continued strong growth for polypropylene in all product areas. Polypropylene film will continue to compete with cellophane and other plastic films in selected packaging markets and should grow at about 15 percent per year over the next few years. We also expect the use of glass-fiber reinforced polypropylene molding materials (still a small market at about 10 million lbs) to increase rapidly. Hercules, Standard Oil (Indiana), Shell, and Standard Oil (New Jersey) are the largest producers of polypropylene.

INDUSTRY ECONOMICS

Over the next five-year period the new fixed capital expenditures required for resin manufacture alone will approximate $2 billion, which is about equal to the total invested in these materials during the past ten years. Possibly another $4 billion will be needed for related petrochemical raw materials, monomer, and fabrication facilities.

The high total capital cost, the high level of capital intensity, and the complex marketing problems of resins will restrict the field largely to current producers with established market positions. As a result of this and the relatively low profits now made on the large-volume resins, the future resins business will not be subjected to the severe price erosion of the past ten years or so, when many new entrants sought essentially to buy their way into the market.

The profitability of resin manufacture will have to improve at least moderately in the next few years in order for the industry to attract the necessary capital to meet these large investment requirements. Comparative levels of return realized on the manufacture of petrochemical raw materials, resins, and fabricated plastic products have varied considerably over the past several years. In general, the average profitability realized from fabrication has been somewhat higher in the most recent years than that obtained from the production of either monomers or resins. During the past several years, the selling prices of fabricated plastic products have increased somewhat, following the general upward pricing trend of most industrial and consumer products. In contrast, the selling prices of polymer raw materials have until recently decreased moderately or about held their level, while those of resins have continued to decrease significantly. In 1969, prices were relatively firm in both basic petrochemicals (e.g., monomers) and resins, and we believe that the average return on investment

TABLE 17

POLYPROPYLENE MARKETS 1970*
(% of Total Demand, by Weight)

Textile uses (as fiber for carpeting, other uses)	27
Packaging	16
Transportation equipment (mainly automotive)	11
Housewares	9
Appliances	6
Toys, dolls and games	5
Export	12
All other uses†	14
Total	100
Production (billion lbs.)	1.0

* Source: Modern Plastics, 48(1), Jan. 1971 and Arthur D. Little, Inc., estimates.

† Includes: luggage, electrical uses, pipe and conduit, other.

from monomer and resin manufacture was closer to that of fabricated plastic products in that year than in any one of the previous five years. We further believe that all three of these sectors of the plastics industry (monomer, resin, and fabricated products) were most profitable in 1969 than the basic chemical industry as a whole. Because of the poor economic conditions existing in many industries in 1970, it is more meaningful to use 1969 as a more typical business year for making financial comparisons.

The Federal Trade Commission - Security and Exchange Commission (FTC-SEC) Quarterly Financial Reports indicate that for 1969 as a whole the return on total investment (i.e., gross fixed assets plus working capital, both taken at year end) in the basic chemical industry was 8.0 percent before Federal Income taxes. Working capital (i.e., current assets minus current liabilities) was about 18 percent of total investment in that year. In contrast, this return was only 6.1 percent in 1970. The company sample that makes up the FTC-SEC's Basic Chemicals category includes most of the major producers of resins.

An average 1969 pretax return on investment of approximately 10.5 percent was calculated for 16 large chemical-plastic companies (Allied Chemical, American Cyanamid, Celanese, Dart Industries, Diamond Shamrock, Dow, du Pont, Ethyl, Foster Grant, Grace, Hercules, Monsanto, Reichhold, Rohm & Haas, Stauffer, and Union Carbide). Several of these chemical companies reported that their plastics operations were among the most favorable parts of their businesses in 1969.

Monomers

We expect that the polymer raw material prices (monomers and intermediates) will remain essentially stable or increase only moderately over the next one to two years and may be somewhat lower than they now are by 1975. By 1975 the U.S. chemical industry will likely have freer access to imported naphtha, which could result in a lower cost for ethylene and other important plastic raw materials or at least keep raw material prices at essentially current levels. We also believe that the next few years will see somewhat lower unit production costs as a result of increasing operating rates in the much larger petrochemical plants that have been constructed in the past few years. Debottlenecking, which will permit moderately increased production from these new large facilities without substantial increases in fixed capital, will be another important factor in lowering the overall unit cost and improving the profitability of monomer production and also in preventing prices from rising much if at all.

As noted in Part I, two of the most important raw materials for resin production are ethylene and vinyl chloride monomer. The supply-demand balance on each of these products was very favorable in 1969, and we estimate that pretax returns of 10 to 15 percent on total investment were realized that year by the producers with large competitive plants. Profitability in 1970 was lower than this level for these chemicals.

For example, we estimate that an ethylene plant operating in 1969, competitive in size with the largest in the industry (about 1 billion lb per year of design capacity) and built on the Gulf Coast as a grass roots plant, would have required a gross fixed investment of about $48 million. The net production cost of ethylene in such a unit, using as raw materials a mixed stream of approximately one third ethane and two thirds propane (a common feedstock for ethylene manufacture on the Gulf Coast), was about 1.8 cents per pound if the plant operated at 90 percent of its design capacity. Raw materials constituted about 57 percent of the cost of production before by-product credits and 95 percent after such credits. (By-product credit in this case is 1.2 cents per lb, derived largely from propylene and a crude butylene-butadiene mix plus some value for pentenes and pentane and other products including fuel gas.) We believe, therefore, that a realistic average net selling price for ethylene in 1969 was about 3 cents per pound and that a pretax profit of approximately 1 cent per pound was realized on ethylene manufacture. The U.S. Tariff Commission reported that the average delivered price of ethylene in 1969 was 3.3 cents per pound.

We believe that a 10 percent return level obtained for vinyl chloride monomer in a large grass-roots plant (500 million lbs) operated at approximately 90 percent of design capacity in 1969. With an ethylene cost of 2.8 cents per pound (transfer price for a basic producer) and chlorine at 2.2 cents per pound, we estimate the cost of manufacture of vinyl chloride monomer at 3.8 cents per pound. Assuming a net selling price of 4.5 cents per pound for vinyl chloride monomer and a total sales, general, and administrative expense factor (SG&A) of approximately 7 percent of sales (the same as with ethylene), pretax profit would be 0.4 cent per pound.

In both cases, new monomer units constructed at existing chemical complex sites would require less fixed plant investment than a grass roots plant in our example (since the offsite investment would be less) and would thus earn a somewhat higher return on fixed investment than our examples indicate (Table 18).

Resins

Nearly all of the virgin resin is sold by the large resin producers, but the secondary resins, or those based on scrap plastic, are sold by the reprocessors.

Resin Producers. We estimate that selected producers of resins achieved pretax returns of at least 12 percent on total investment in 1969. This was higher than those realized in each of the preceding five years. Those firms whose product mix was composed almost completely of

TABLE 18

TYPICAL COSTS AND PROFITABILITY OF
PETROCHEMICAL RAW MATERIALS FOR PLASTICS 1969*
(Grass Roots Plant; Gulf Coast Location)

	Ethylene	Vinyl chloride monomer
Designed plant capacity (MM lb./year)	1000	500
Plant investment (MM $)	48	14.5
Production (MM lb./year)	900	450
Plant investment per unit of production (¢/lb.)	5.3	3.2
Cost of manufacture	¢/lb.	¢/lb.
Raw Material		
Propane (1.13 lb. @ 0.9¢/lb.)	1.0	---
Ethane (0.65 lb. @ 1¢/lb.)	0.7	---
Ethylene (0.5 lb. @ 2.8¢/lb.)	---	1.4
Chlorine (0.67 lb. @ 2.2¢/lb.)	---	1.5
Operating labor and supervision	0.1	small
Depreciation (@ 10% of investment)	0.5	0.3
All other costs (catalysts, utilities, maintenance, etc.)	0.7	0.6
Total cost of manufacture	3.0	3.8
By-product credit	-1.2	---
Net cost of manufacture	1.8	3.8
Profitability		
Net selling price (FOB plant)	3.0	4.5
Cost of manufacture	-1.8	-3.8
	1.2	0.7
SG&A expense	-0.2	-0.3
Pretax profit	1.0	0.4
Pretax return on total investment†	15.5%	10%

* Source: Arthur D. Little, Inc., estimates.

† Assumes that plant investment is 82% of total investment.

general-purpose-grade materials obtained returns lower than 12 percent. We believe, for example, that in the case of the PVC resins, the best companies in the industry in terms of product mix and overall competitive position likely realized at least a 12 percent pretax return on their PVC operations. We estimate that in a large (150 million lb per year) PVC plant operating at 90 percent of design capacity and using vinyl chloride monomer at 4.5 cents per pound delivered (e.g., captive monomer), the cost of manufacture of general purpose PVC homopolymer would be about 7.7 cents per pound. Assuming a net selling price of 10.2 cents per pound, which we think was realistic as the average during 1969, and assuming an overall SG&A expense item of about 11 percent of sales (which would support relatively little technical expense), the pretax return would be about 1.4 cents per pound, or approximately 12 percent on total investment (Table 19). We believe that the pretax returns realized on some of the higher-priced specialty grades of plastic materials were in excess of 20 percent in 1969.

We anticipate that the overall profitability of resins will continue to improve somewhat in the future after declining again in 1970 and 1971. This improvement could be most significant in the short term (i.e., 1972 and 1973), if the economy shows renewed growth and continues to improve in 1972 and 1973.

Reasonably stable raw material costs, improving plant economics, and a better supply-demand balance will all contribute to better returns for resin producers during the next few years. The very large plants constructed within the past few years and those now being built to produce polyethylene and polypropylene (and, to a lesser extent, styrene resins and those based on vinyl chloride) are expected to show improved economics of manufacture. Debottlenecking and rising operating rates will result in lower unit costs; although labor costs are rising by at least 7 percent per year, they are a very small part (e.g., 5 percent or less) of the total cost of manufacture. We believe that on average the future supply-demand balance will be more favorable than that which has existed over the past several years, and that the return on investment from large-volume resin production will improve to levels approaching those of the early 1960's (e.g., 15 percent and over). We expect returns to improve enough to attract the substantial new capital required to sustain a tonnage growth rate of 12 percent per year in resin output. Overcapacity and the resulting price decreases reduced profits to unacceptably low levels in 1967 and more particularly in 1968 and 1970. Profitability is lower again this year (1971). During 1970, and in other years such as 1967 and 1968 when there was considerable oversupply, some prime virgin resin was sold as ''off-grade'' resin.

Reprocessors. The reprocessors, who sells secondary resin, has had his profit margin reduced by the rapid fall in prices of virgin resins, as mentioned in the section ''Growth and Price Trends.'' Therefore, when possible, the reprocessor attempts to sell an ''up-graded'' compound based on reprocessed scrap. As an example, some dark colored polypropylene

TABLE 19

TYPICAL COST AND PROFITABILITY OF POLYVINYL CHLORIDE HOMOPOLYMER 1969*

(Grass Roots Plant; Gulf Coast Location)

Designed plant capacity (MM lb./year)	150
Plant investment (MM $)	13
Production (MM lb./year)	135
Plant investment per unit of production (¢/lb.)	9.6
Cost of Manufacture	¢/lb.
Raw material	
Vinyl chloride monomer (1.06 lb. @ 4.5¢/lb.)	4.8
Operating labor and supervision	0.3
Depreciation (@ 6-2/3% of investment)	0.5
All other costs (catalysts, utilities, maintenance, etc.)	2.1
Total cost of manufacture	7.7
Profitability	
Net selling price (FOB plant)	10.2
Cost of manufacture	-7.7
	2.5
SG&A Expense	-1.1
Pretax profit	1.4
Pretax return on total investment†	12%

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* Source: Arthur D. Little, Inc., estimates.

† Assumes that plant investment is 80% of total investment.

compounds used by the automobile industry for items such as duct work are based on scrap as a raw material. In these situations, where the reprocessor can ''tailor make'' a product for a specific use, he can improve his profit margin somewhat. Another way for a reprocessor to try and gain better overall profits is to sell a fabricated item based on scrap plastic. The reprocessor then competes with other fabricators who use compounds.

Plastic materials used by the reprocessor are obtained mainly from the basic resin producers and fabricators in the form of strands, chunks, sheets, film, molded items, etc. (as described in Part I). He pays from 3/4 to 1-1/2 cents per pound for strands and chunks; 2 to 5 cents per pound for floor sweepings; 1 to 1-1/2 cents per pound for flexible PVC scrap; baled film scrap costs him about 4 cents per pound, and normal polyolefin regrind 5 cents per pound. High quality scrap can sometimes command a price as high as 10 cents per pound, and some scrap is so poor in quality that it can be purchased merely for the transportation costs.

Raw material costs for scrap have been changing: for example, in 1962, the reprocessor paid about 6 cents per pound for scrap that costs him no more than 2 cents per pound today. Unfortunately, with today's low scrap price the scrap seller has lost his incentive to accumulate, segregate, and bale scrap; whereas, he was willing to sell all of his scrap when he received the 6 cents per pound price F.O.B. his location.

Transportation and storage is another important cost of reprocessing. Usually scrap has very low ''bulk density'' and quantities of scrap are often held in storage for comparatively long periods. Both factors are dependent on volume, thus shipping scrap is typically more expensive than shipping the dense granulated resins themselves. In most reprocessing operations, normal transportation costs for the scrap are 1 to 1-1/2 cents per pound. Shipping greater distances, such as cross-country, is usually prohibitive; however, if ship transport is available, scrap can be shipped, for example, from the Gulf Coast to New Jersey for 1.5 to 1.8 cents per pound.

Some reprocessors merely purchase scrap, package it, and sell it as such to companies in Hong Kong, Thailand, Taiwan, Korea, Brazil, and Italy. Baled scrap can be shipped at a cheaper price than the reprocessed material in pellet form, based on the difference in Tariff rates. Shipping baled scrap from New Jersey to Hong Kong costs about 2-1/2 cents per pound. If the scrap (particularly film) can be obtained for 3 cents per pound, it may command a price of 6 to 7 cents per pound in Hong Kong, and the scrap dealer can earn a profit.

An essentially fixed cost for the reprocessor is the cost of sorting and reprocessing the scrap. Losses during the sorting, which removes the very badly contaminated scrap, can be as high as 10 percent. Reprocessing costs vary from 4 to 4.4 cents per pound. If reprocessing is done on a toll basis, the charge is commonly about 7 cents per pound, depending upon the production volume. As is true in most manufacturing, reprocessing unit costs can be reduced somewhat as the size of the operation is increased.

The following are examples of reprocessing economics. (1) Polypropylene scrap can be purchased for 1-3/4 cents per pound, transportation costs are 1/2 cent per pound, and reprocessing costs are 5-1/2 cents per pound. Thus, total costs are 7-3/4 cents per pound. This product can sell for about 9 cents per pound, which permits a gross margin of about 1-1/4 cents per pound. (2) Flexible PVC scrap can be purchased for 1 cent per pound, transportation costs are 1 cent per pound, and the reprocessing, which includes hand picking through the scrap, chopping, granulating, and blending, costs another 4 cents per pound to give a total cost of about 6 cents per pound. But the rate of production through the extruder is reduced perhaps fourfold, because screen packs are needed. Thus, the real costs are greater than 6 cents per pound. This product can be sold for 13 cents per pound or about 2 cents per pound below the virgin compound.

Plastic Products

A meaningful measure of the average profitability of fabricated plastic products operations is difficult to develop, because there are over 2500 such companies and over 5000 such manufacturing plants in the U.S. However, one measure of return can be calculated from the data reported in the FTC-SEC Quarterly Financial Report under the category Rubber and Miscellaneous Plastic Products.[3] The 1969 pretax return on total investment reported for this category was 9.2 percent. (Working capital was 28 percent of total investment for this product category.) We believe that the profitability of plastics products manufacture is somewhat higher than that realized on miscellaneous rubber products. After subtracting the financial data of the big five rubber companies (Goodyear, Firestone, Goodrich, Uniroyal, and General Tire) from this category, we found that the balance of the category has a return of 10.2 percent.

Another measure of profitability in the fabricated plastics industry is the financial statements of individual producers of fabricated plastic products. This approach also is difficult because the major producers of fabricated plastics tend to be divisional operations of very large companies for which the specific financial statements of the plastic fabrication operations are not available. Furthermore, the companies that fabricate plastic products as their primary business tend to be small, privately owned companies where meaningful financial information is very difficult to obtain. However, there are some publicly owned companies that have sales of at least $20 million annually that are large fabricators of purchase plastic materials. Considering eleven of these companies (which are part of the FTC-SEC sample of producers of miscellaneous rubber and plastic products), the pretax return on the fixed investment (gross property, plant, and equipment) averages 17.5 percent, although there are wide variations among the companies selected (Table 20). If we assume that the fixed investment was also about 72 percent of the total investment for those companies, as was the case for the broad industry sector, the average return on total investment is about 12.6 percent. The average pretax return on investment for all manufacturing companies according to the FTC-SEC data was 10.7 percent in 1969.

MAJOR COMPANIES

Production of Resins

Because of the rapid growth of the plastics industry, the number of resin producers increased from 145 in 1950 to a peak of 337 in 1964. Since 1964, however, the number has decreased to the 270 reported for 1969, as reported by the U.S. Tariff Commission. We expect that the number will stay at about the 250 level during the next few years. About 30 to 35 companies produce the bulk of the resins. These major participants include many of the large chemical, petroleum, and rubber producers and a variety of other large industrial firms including Borden, Borg-Warner, Eastman Kodak, and General Electric.

Resin plants tend to be located in certain sections of the U.S. In the case of polyethylene and polypropylene, the resin plants are located near the source of petroleum raw materials, i.e., in the Gulf Coast area; PVC and polystyrene resin plants are generally located near the consuming markets, which are in the industrial centers of the eastern half of the U.S. and in the Los Angeles region.

Several of the important producers of resins diversified into the business during the past 10 to 15 years in an effort to exploit the fast-growing plastics market and, in the case of the oil companies, to further upgrade their basic petroleum resources. To such new products, diversification into resin manufacture appeared to offer: (1) the advantages of substantial raw material utilization (in some cases), (2) rapid growth, (3) opportunities for large investments, and good levels of return. Also, the continuing encroachment of plastics on traditional markets for paper, wood, glass, and metals; the international potential; and an improved corporate image for investors (in those years when plastics were ''glamour'' stocks) were other incentives. However, many companies entered the plastic materials industry without a full understanding of the very complex marketing and technical product requirements involved. To be successful, a resin producer must offer the following: (1) very strong overall customer service (which requires strong technical service, unusual distribution capability, operational flexibility, and strong application research resources); (2) some specialty resins in addition to commodity types;

TABLE 20

SALES AND PROFITABILITY OF TYPICAL PLASTICS FABRICATORS, 1969*

Company	Approximate sales (MM $)	Pretax return on fixed investment (%)
Amerace-Esna	164	16.3
American Biltrite Rubber	167	8.7
Dayco	321	16.2
O'Sullivan	16	21.8
Pioneer Plastics	24	30.0(est.)
Plymouth Rubber	33	8.0
Polymer Corp. (Div. of ACF Industries)	25	18.1
Richardson	127	18.8
Rogers	28	11.5
Rubbermaid	64	26.0
Woodall Industries†	30	18.0
Average		17.5

*Source: Company reports.

†1968 data; acquired in 1969 by Libby-Owens-Ford and data for later year was not available as such.

(3) a reasonable level of captive use of resin for making upgraded products; (4) strong management commitment and continuing involvement.

The largest producers of the major thermoplastic resin that are of particular interest to this study had a capacity of about 13.8 billion pounds of the Big 5 thermoplastics as of January 1, 1971 (Table 21). Most leading companies produce several different types of resins, including both thermoplastic and thermosetting types. Exceptions are Borg-Warner (which makes only ABS) and Foster Grant (which concentrates on polystyrene, but also has a small position in nylon plastics). A reasonably wide product line allows the relatively high technical and marketing costs associated with resins to be allocated to several products rather than to one or two.

Changes in Marketing. Significant changes have been occurring in the product lines of many of the long-term leading producers, and several "new" companies have entered the resin business in the past decade.

Allied Chemical, for example, was formerly a major producer of polyesters and alkyds, but within the past three years Allied has sold off these operations and entered the production of HDPE (by acquiring a plant from W. R. Grace) and PVC plastics (by licensing technology from Japan). Allied is also putting greater emphasis on some of the more specialized types of plastic materials, such as the nylons, fluorocarbons, and urethanes.

A few years ago American Cyanamid was a minor producer of styrene plastics, but it withdrew by leasing its plant to Shell. At one time the leading producer of polyester resins, Cyanamid has more recently deemphasized the polyesters and aggressively entered the methacrylate plastic field (where it now ranks third after Rohm & Haas and du Pont), and the urethane polymer area. Cyanamid continues to lead the industry in amino plastics (urea and melamine resins), as it has for many years.

Borg-Warner's Marbon Division is the largest supplier of ABS plastic and is considered to be the technical leader. Because of the very high quality and relatively firm price of the ABS materials over the years, the parent firm has been able to sustain the development of a Chemicals and Plastics operation (1970 sales of about $131 million) on the basis of essentially the one product line of ABS materials. Borg-Warner established Borg-Warner Machines to make and sell fabricating equipment to the plastics and rubber processors in an effort to capitalize on its corporate strength in the mechanical systems and general machinery areas.

Dow has discontinued its modest participation in two large-volume plastics, PVC and polypropylene. The company is now concentrating on the sale of vinyl chloride monomer and aggressively maintaining its leadership in the high-volume styrene plastics, and remaining competitive in LDPE and HDPE.

TABLE 21

U.S. CAPACITIES OF LARGEST PRODUCERS OF MAJOR THERMOPLASTICS, AS OF JANUARY 1, 1971
(Millions of Pounds Per Year)*

Producer	LDPE	HDPE	PP	PS	ABS	PVC	Total
Allied Chemical		250				200	450
Borden						240	240
Borg-Warner (Marbon)					240		240
Celanese		250					250
Dart Industries	330†		90†	140	40		600
Diamond Shamrock			90			250	340
Dow	570	235		715	50		1570
DuPont	600	150					750
Eastman Kodak	250		90				340
Ethyl						150	150
Foster Grant				300			300
B. F. Goodrich					30	650	680
Gulf	440	100					540
Hercules		80	600				680
Koppers‡	180	120		300			600
Monsanto		180		400	170	150	900
National Distillers	430	190§					620
Phillips Petroleum	95	160	85				340
Shell			300	85			385
Standard Oil (Indiana)		100	400	265			765
Standard Oil (New Jersey)	350		300				650
Tenneco						260	260
Union Carbide	1050	240		260		320	1870
Uniroyal					200	130	330
Totals	4295	2055	1955	2465	730	2350	13,850

* Source: Modern Plastics, 46(7) July 1969; 48(2) February 1971; and 48(3) March 1971; and Plastics World, 29(10) Oct. 1971.

† Jointly owned with El Paso Natural Gas

‡ Jointly owned with Atlantic-Richfield.

§ Jointly owned with Owens-Illinois

Key:

LDPE - low density polyethylene
HDPE - high density polyethylene
PP - polypropylene
PS - polystyrene
ABS - acrylonitrile-butadiene-styrene
PVC - polyvinyl chloride

Monsanto has sold its relatively small LDPE plant to Northern Natural Gas (a new large producer of LDPE) in an effort to phase out of this competitive segment of the resins industry. Monsanto has also discontinued the manufacture of vinyl chloride copolymers (as have other PVC producers), but is aggressively maintaining its position as the second largest factor in styrene plastics and the major producer of polyvinyl butyral.

National Distillers had two joint ventures in the polyethylene field: a long-standing joint ownership with Owens-Illinois of a HDPE plant and a proposed joint venture with U.S. Steel in LDPE via their jointly owned company, Reactive Metals. For several years National Distillers independently owned and operated two LDPE plants. Ownership of its LDPE plants was transferred to Reactive Metals, which would have given U.S. Steel equity in LDPE, in addition to its wholly-owned polystyrene plant, which recently became operative. However, because of anti-trust considerations, the U.S. Government would not allow the transfer of ownership of the LDPE plants to Reactive Metals.

A few years ago Phillips Petroleum was forced by the U.S. Government to sell its polypropylene plant (bought by Diamond Shamrock) as part of an anti-trust consent decree that also involved National Distillers. Phillips, one of the technical leaders, is also one of the largest manufacturers of HDPE and is now producing polypropylene again in a new plant built under the provisions of the consent decree.

Standard Oil of Indiana, which entered the plastics business through acquisitions of polystyrene and polypropylene producers, has also constructed a plant to make HDPE using its own process. The company has recently expanded all its resin plants.

Sales. According to our estimates the total plastics sales of the major resin producers in 1969 was $5.9 billion (Table 22). In the aggregate, plastics sales account for about 7 percent of the total sales of all these companies taken together and range from as low as 1 percent of sales for Gulf Oil and General Electric to nearly all of the business of Foster Grant. Our figures include total sales (including foreign) of both resins and fabricated platic products. We do not, however, include sales of synthetic fibers or formulated paint products. In the case of du Pont, however, we have included sales of cellophane (packaging film), which approximated $125 million in 1969. Some companies report some information on total plastics sales, but the usual practice is to combine plastics sales with those of other allied product categories such as fibers (in the case of Allied Chemical), chemicals (Borg-Warner and B. F. Goodrich), or packaging materials (Dow).

New Resin Development. du Pont, General Electric, and Union Carbide have consistently led the industry in the introduction of new chemical compositions of resins. American Cyanamid and Dow were quite active in

TABLE 22

PLASTICS SALES OF MAJOR PRODUCERS, (1969)*

Company	Million $		Plastics as approximate % of total sales
	Total Sales (worldwide)	Approximate plastics sales†	
Allied Chemical	1315	130	10
American Cyanamid	1090	150	14
Ashland Oil	1151	75	7
Borden	1740	200	12
Borg-Warner (Marbon)	1090	140	13
Celanese	1250	125‡	10
Dart Industries	710	200	28
Diamond Shamrock	540	100	18
Dow	1800	610	34
DuPont	3630	800‡	22
Eastman Kodak	2750	150	5
Ethyl	509	100	20
Foster Grant	74	70	95
General Electric	8448	75	1
B.F. Goodrich	1230	150	12
W.R. Grace	1782	125	7
Gulf	6200	75	1
Hercules	746	90	12
Koppers	533§	64§	12
Mobay ¶	90 (est.)	25	28
Monsanto	1940	425	22
National Distillers	1082	100	9
Occidental Petroleum (Hooker)	2100	100	5
Phillips Petroleum	2200	110	5
Reichhold	182	130	72
Rohm & Haas	446	270	60
Shell	4280	75	2
Standard Oil (Indiana)	4320	125	3
Standard Oil (New Jersey)	16,900	75	small
Standard Oil (Ohio)	1160	65	6
Stauffer Chemical	500	80	16
Tenneco	2500	75	3
Union Carbide	2900	725	14
Uniroyal	1550	100	6
Total	78,718	5934	

* Source: Company reports and Arthur D. Little, Inc., estimates.

† Includes resins, resin emulsions, and fabricated products (e.g., industrial products and packaging film).

‡ Includes sales of cellophane.

§ Includes half of the sales of the Sinclair-Koppers joint venture.

¶ A unit of Baychem, 100% owned by Farbenfabriken Bayer.

the earlier years but have not introduced a truly new resin composition which has attained commercial significance since the early 1940's. Hercules and Mobay have each introduced two basic compositions in the last 15 years. The Mobay developments were derived essentially from basic research done by its parent company, Bayer in W. Germany.

Fabrication of Plastic Products

As indicated earlier, the fabrication of semifinished or finished products from resins is shared about equally by the basic resin producers, end-product companies (i.e., large users of plastic products), and independent fabricators. The companies in the first two categories are among the largest industrial units in the country, whereas the independent fabricators are primarily small privately owned manufactures. Much of the acquisition activity in the plastics industry has been concerned with plastic fabrication. Materials producers are continuing a long-time trend of integrating forward, and end-product companies are integrating backward, trends that we believe will continue to put pressure on the independent fabricators and further reduce their share of the total fabrication business.

Resin Producers. The major areas of forward product integration by the major resin producers include: flexible film, adhesives, rigid sheet, containers, other molded and extruded products, coated fabrics, pipe, protective coatings, and foamed products (Table 23). Captive upgrading to processed products is generally desirable because it permits a higher operating rate of the resin plant and gives the resin producer somewhat greater control over his marketing channels. The resin producers are continuing to selectively acquire fabricators. For example, a couple of years ago American Cyanamid bought Standard Coated Products, a producer of plastic-coated wall covering to add to its building products business, Standard Oil of Indiana acquired a producer of housewares and Minnesota Plastics, a general products molding company. About three years ago, U.S. Steel, now a substantial new producer of polystyrene, acquired the Plastics Division of GATX, a major supplier of automotive and appliance molded parts with current sales of about $20 to 25 million, and Continental Oil, a PVC resin producer, acquired Vinyl Maid, a producer of PVC and other plastic bottles.

Forward integration is not achieved without some risk: for example, in relations with resin customers; in matching products of the materials operation with requirements of the processing operation; and in profitably marketing the fabricated products, which require much different marketing techniques. Thus, there are instances of resin companies entering certain areas of fabricated plastics and then later retrenching. For example, Allied Chemical sold its plastic pipe operation; Celanese bought and then soon thereafter resold (to Cities Service) Fesco, a major producer of plastic housewares; and Dow has discontinued its production of plastic bottles.

TABLE 23

FORWARD PRODUCT INTEGRATION BY MAJOR RESIN PRODUCERS - 1970*

Company	Flexible Film	Adhesives	Rigid Sheet	Other Molded and Extruded Products	Bottles or Containers	Coated Fabrics	Pipe	Protective Coatings	Foamed Products
Allied Chemical	X	X	X	X					
American Cyanamid		X	X	X		X			
Ashland Oil		X		X					
Borden	X	X	X	X		X		X	
Borg-Warner (Marbon)		X	X	X			X		
Celanese	X		X	X			X	X	
Dart Industries	X		X	X	X	X			X
Diamond Shamrock	X	X	X			X			X
Dow	X		X		X		X		X
DuPont	X	X		X		X	X	X	
Eastman Kodak	X	X	X	X					
Ethyl	X			X	X		X		
Foster Grant				X	X				X
General Electric		X	X	X		X		X	
B.F. Goodrich	X	X	X	X		X	X		X
W.R. Grace	X	X		X	X	X			
Gulf		X							
Hercules	X	X		X	X				
Koppers	X	X	X	X	X			X	X
Mobay (Bayer)			(Essentially no forward integration)						
Monsanto	X	X	X	X	X				
National Distillers	X								
Occidental Petroleum (Hooker)	X	X				X		X	X
Philips Petroleum	X		X	X	X		X		
Reichhold		X	X					X	
Rohm & Haas	X		X						
Shell			(Essentially no forward integration)						
Standard Oil (Indiana)	X			X					
Standard Oil (New Jersey)	X		X						
Standard Oil (Ohio)			X	X			X		
Stauffer	X		X	X		X	X		
Tenneco	X	X	X	X	X				X
Union Carbide	X		X			X			X
Uniroyal		X	X	X		X	X		X

* Source : Arthur D. Little, Inc.

National Distillers' plastic pipe operation has been acquired by Olin, and Union Carbide unsuccessfully tried to enter the plastic container field. Borg-Warner has also recently discontinued the production of certain fabricated plastic products which were reported to be loss operations for the company. Koppers recently sold off some of its reinforced plastics fabricated products.

End-Product (Manufacturing/Packaging) Companies. The companies that fabricate plastics include many of the largest and medium-sized industrial firms in the country, for which plastic often represents only one of many basic raw materials fabricated by these firms. In most cases, the more traditional raw materials, mainly metal (particularly steel), as well as paper, wood, textiles, and rubber are still more important basic materials than plastics. Several end-product companies fabricate large amounts of plastics materials and some also produce resins (relatively small quantities of selected materials in most cases) but by and large they purchase their resins and molding materials from outside sources (Table 24). We believe that in the future these types of companies will continue to do relatively more of their own fabricating of plastic parts and will, therefore, increase their proportionate share of consumption of resins.

In general, this manufacturer/packager segment has been particularly active in acquiring fabricators in the last few years. For example, Beatrice Foods has conducted an aggressive total acquisition program that has included makers of plastic boats and resin-based coatings. This company also makes styrene, vinyl acetate, and acrylic-based resins through its acquisition of Polyvinyl Chemicals (a division of Stahl Finishes) a few years ago. Within the last two years, Phillip Morris, Crown Zellerbach, Dexter, Anchor Hocking, Libby-Owens-Ford, National Gypsum, Pacific Clay Products, U.S. Gypsum, General Foods, and National Biscuit have all acquired relatively small fabricators or formulators of resins and plastics.

Independent Fabricators. There are several hundred independent fabricators that produce plastic products as their primary business. The most recent Census of Manufacturers (1967) listed approximately 5,000 establishment (individual plants) in SIC category 3079, Miscellaneous Plastic Products.[4] As might be expected, over half of these businesses had under 20 employees. The value of their shipments of plastic products was about \$5 million, indicating an average sales per establishment of approximately \$1 million in 1967. The 1969 Annual Survey of Manufacturers (ASM) indicates that sales of this industry category (3079) increased to about \$7 billion in that year. Because most independent fabricators are single plant operations, average sales per company are on the order of \$1 to 2 million. The 1967 Census of Manufacturers also indicated that 661 establishments in SIC category 2821, Plastics Materials and Resins, had shipments of about \$3 billion; the 1969 sales of those products according to the ASM survey were about \$4 billion. On this latter basis the approximate sales income per resin plant is now about \$6 million, or

TABLE 24

TYPICAL PROCESSORS OF PLASTIC MATERIALS AMONG END PRODUCT COMPANIES*

End Product Category	Typical Processors
Food and related products	Beatrice Foods†, National Dairy Products, General Mills†
Tobacco	R.J. Reynolds, Philip Morris†
Textile mill products	Burlington Industries, Chelsea Industries, Ludlow
Paper and allied products	Bemis, Container Corp., Crown Zellerbach, Dexter†, Mead, International Paper, Maryland Cup, Scott Paper†
Stone, clay, and glass products	Owens-Illinois†, Certain-teed Products, Flintkote, Garlock, Johns-Manville, Norton, Anchor Hocking, Lenox
Fabricated metals	American Can†, American Standard, Continental Can, H.H. Robertson†
Machinery, except electrical	Outboard Marine, Cincinnati Milacron, Crompton & Knowles, White Consolidated Industries, Pitney-Bowes
Electrical machinery and related products (including communications equipment)	General Electric†, Westinghouse†, Hoover, Singer, Sunbeam, Emerson Electric, American Telephone (Western Electric), IBM
Transportation equipment (mainly automotive)	American Motors, Borg-Warner†, Chrysler, Ford Motor†, General Motors, McCord, A.O. Smith, North American Rockwell†, ACF Industries.†
Instruments and related products	Ametek, 3M†, Johnson & Johnson
Miscellaneous manufacturing	Brunswick, Mattel, Parker Pen, Armstrong Cork†, Bath Industries (Congoleum Nairn)

* Source: Company and trade announcements

† Also produces selected types of plastic resins

about four times that of the average fabricating establishment. However, the largest fabricating resin plants are operated by companies that do not appear in SICs 3079 or 2821, because the primary business of the large fabricators and large resin producers are in broader SIC sectors such as SIC 371 Motor Vehicles, and 281 Basic Chemicals.

The approximate cost of all raw materials (plastic and other) for the small independent fabricators is somewhat less than half the value of shipments (sales). We estimate that the cost of resins and plastic additives alone represents approximately one third of the total sales value of these fabricators.

PART III

THE PLASTICS CYCLE

In addition to the segments of the plastics industry mentioned in the previous two sections, the plastics cycle (Figure 26) through which all articles pass includes the manufacturer/packager, who assembles the plastic or plastic-containing product or fills a plastic container; the wholesaler/retailer, who is responsible for distributing the product to the consumer; and finally the consumer, which includes not only the individual householder but institutions such as hospitals, restaurants, airlines, and various industries.

The resin producers, who are the largest companies (see Part II), convert petroleum raw materials or monomers into polymer or compound. Therefore, they determine the chemistry of the plastic item. If the product is a special compound, or it requires a small production run, the compounding is usually not done by the resin producer, but by a smaller company (the compounder) who specializes in these operations. In a few instances, the compounder resells the finished compound to the resin producer; normally the compounder sells it directly to the fabricator.

The fabricator often also acts as a compounder. Thus, compounding can be carried out by the resin producer, compounder, or fabricator. However, the major function of the fabricator is to take the granulated or pelletized resin and transform it into a shaped article, which may be finished or semi-finished. If it is semi-finished, the article goes to a converter, for example, fabricated film is converted to plastic bags.

The finished article normally goes directly to the manufacturer/packager. This segment, and in particular the packager, is the major decision maker in the cycle. He is the one who decides just what type of package or plastic article he wishes to use. Often a manufacturer sells plastic products to another. As an illustration, the manufacturer of plastic-coated wire usually sells his product to another manufacturer, for example, one who produces television sets.

In some cases fabricators sell directly to the wholesaler/retailer segment, for example, plastic film is sold to supermarkets for wrapping produce and meat. Here, the retailer also is the packager. Similarly,

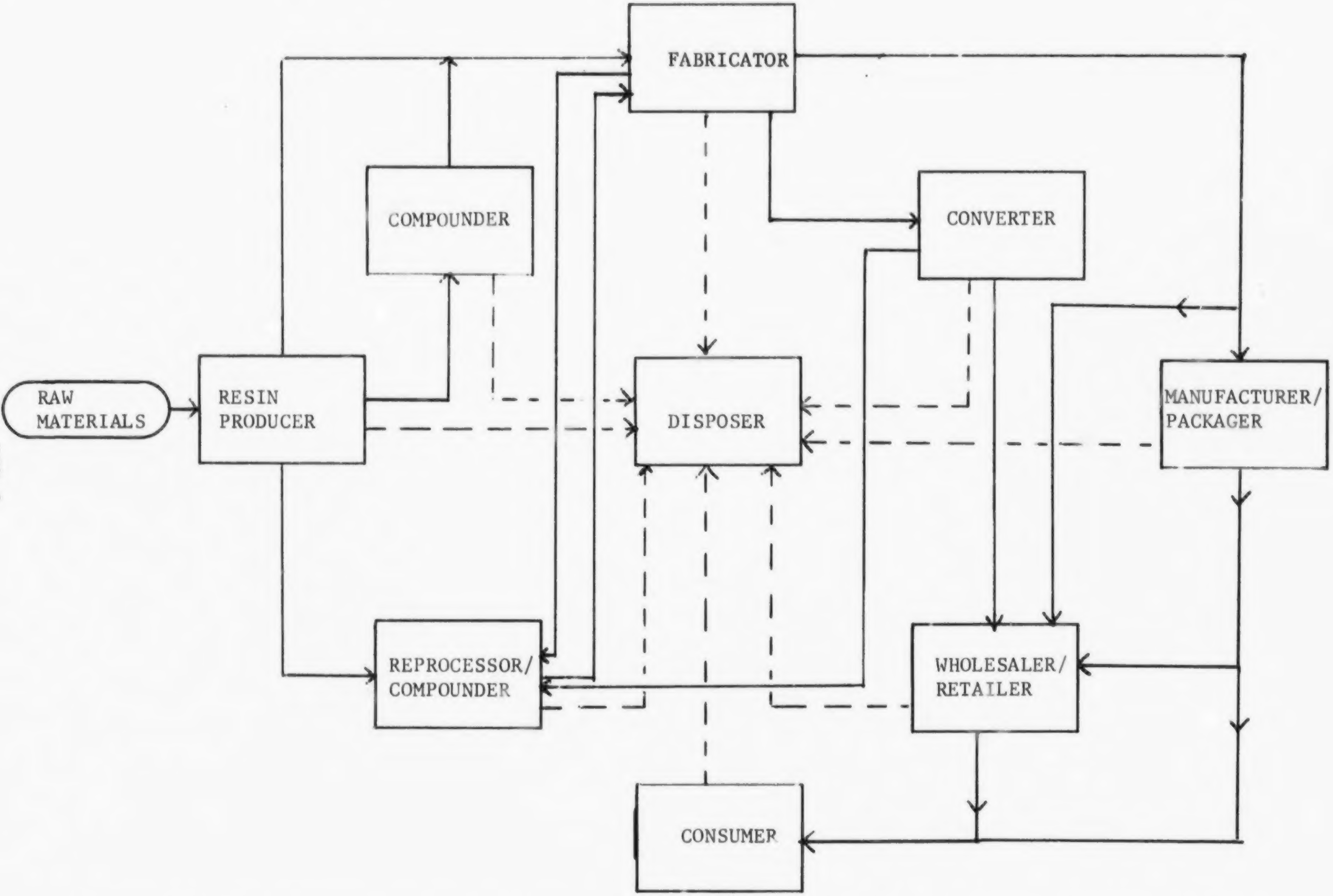

RAW MATERIALS
RESIN PRODUCER
COMPOUNDER
FABRICATOR
REPROCESSOR/ COMPOUNDER
DISPOSER
CONSUMER
CONVERTER
WHOLESALER/ RETAILER
MANUFACTURER/ PACKAGER

Figure 26. The plastics cycle. All segments of this cycle contribute nuisance plastics to the disposer.

the converter often sells directly to the wholesaler/retailer segment. Note also from Figure 26 that materials flow to the reprocessor from the resin producer, fabricator and converter and then back to the fabricator.

As noted in Part II, integration of operations within the plastics industry is extensive; thus, one company can be resin producer, compounder, and fabricator; and a manufacturer/packager can sometimes operate as fabricator and converter. Figure 26 is meant to show physical flow from operation to operation, rather than between individual companies. Note, also, that as a plastic product is made, starting from the resin, it normally passes through manufacturing facilities that progressively become smaller in size and more dispersed geographically as noted in Part II. The wholesaler/retailer and consumer segments are obviously dispersed according to population density.

The dashed lines in the diagram indicate that all segments of the plastics cycle, including the consumer, generate NP. Thus, there are two major sources of NP--that from the industrial and commercial sectors, and that from the consumer. Significantly, from the point of view of recycling, the stream of NP from the industrial and commercial sectors is less contaminated with other non-plastic wastes than the waste stream from the consumer. The latter contains only a minor amount of plastic wastes.

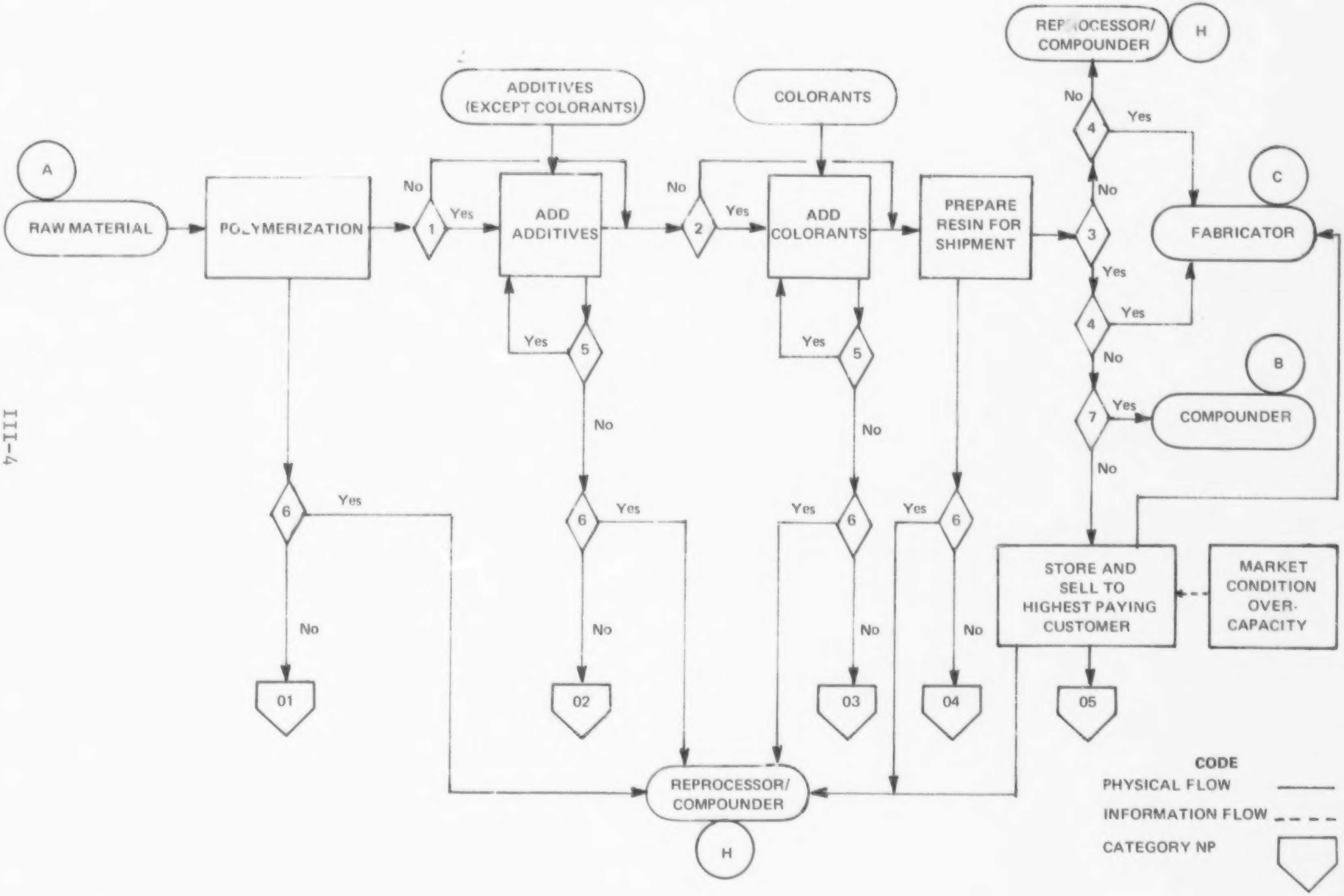
Let us now examine the flow of materials through each of these segments.

THE RESIN PRODUCER

A generalized flow diagram representing the production of the major thermoplastic resins is shown in Figure 27. The decision points are indicated by the diamond-shaped symbols in the diagram and are listed in Table 25. The pentagonal symbols represent various categories of NP. Each NP category has a code number, which is explained in the Appendix. Table 26 is a compilation of the nuisance plastics generated by this segment by category together with estimates of the volume produced in 1970.

Disposal of Scrap Plastic

Note from Figure 27 that NP can be generated during many of the operations of the resin producer: polymerization, addition of additives (including colorants), preparation of the resin for shipment, and storage of the finished product. Another general feature indicated by the figure, as shown, for example, by the compounding operation, is that scrap plastic produced during manufacture can be removed in three different ways: (1)



A
RAW MATERIAL
POLYMERIZATION
1
No
Yes
ADDITIVES
(EXCEPT COLORANTS)
ADD
ADDITIVES
5
Yes
No
6
Yes
No
01
02
2
No
Yes
COLORANTS
ADD
COLORANTS
03
PREPARE
RESIN FOR
SHIPMENT
04
3
4
7
REPROCESSOR/
COMPOUNDER
H
C
FABRICATOR
B
COMPOUNDER
STORE AND
SELL TO
HIGHEST PAYING
CUSTOMER
MARKET
CONDITION
OVER-
CAPACITY
05
CODE
PHYSICAL FLOW
INFORMATION FLOW
CATEGORY NP

Figure 27. The resin producer. Nuisance plastics can be generated during many operations of this segment.

TABLE 25

DECISIONS

---

1. Additives required?
2. Colorants required?
3. Within specifications?
4. Sell to fabricator?
5. Can scrap plastic be recycled in own facilities?
6. Can scrap plastic be sold to reprocessor?
7. Sell to compounder?
8. Does SP have to be colored to be recycled?
9. Sell to converter?
10. Sell to manufacturer/packager?
11. Sell to wholesaler/retailer?
12. Can scrap plastic be sold to fabricator?
13. Sell to retailer?
14. Does SP have to be cleaned to be recyled?
15. Sell to consumer?
16. Discard product?
17. Is product returnable?
18. Can anything be salvaged?
19. Is refuse to be compacted?
20. Is refuse to be shredded, pulverized, or milled?
21. Is refuse to be composted?
22. Is refuse to be incinerated?
23. Is refuse to be disposed of in final disposal area?

TABLE 26

ESTIMATED VOLUME OF NUISANCE PLASTICS GENERATED BY RESIN PRODUCER* (1970)

					1970 Production (Million Pounds)	
Code No.	Type resin	Operation	Physical form	Av. % NP†	Total all production	Total NP
01.11	HDPE	Polymerization	Sweepings, fines, waxes, chunks, wet slurry	0.5	1700	8.5
01.12	LDPE			0.5	4300	21.5
01.13	PP			1.8	1010	18.2
01.14	PS ‡			0.5	3350	16.8
01.15	PVC			2.6	3150	82.0
02,03.11	HDPE	Adding additives and colorants	Strands, chunks, sweepings	0.2	1700	3.4
02,03.12	LDPE			0.2	4300	8.6
02,03.13	PP			0.2	1010	2.0
02,03.14	PS			0.2	3350	6.7
02,03.15	PVC			0.2	3150	6.3
04.11	HDPE	Preparation for shipment	Pellets, powder, sweepings	0.15	1700	2.6
04.12	LDPE			0.15	4300	6.4
04.13	PP			0.15	1010	1.5
04.14	PS			0.15	3350	5.0
04.15	PVC			0.15	3150	4.7
05.11	HDPE	Storage	Pellets, powder, sweepings	0.05	1700	0.8
05.12	LDPE			0.05	4300	2.2
05.13	PP			0.05	1010	0.5
05.14	PS			0.05	3350	1.7
05.15	PVC			0.05	3150	1.6
Total				1.5		201.0

*Source - Arthur D. Little, Inc.

†Percentages stated based on total production of particular resin.

‡All styrene polymers including ABS.

by recycling it in one's own facilites; (2) by selling it to a reprocessor; (3) by removing it as NP.

Following the flow diagram from left to right, the first operation is polymerization. Overall yields in this process are 97 percent or greater with most olefins. However, PVC yields tend to be somewhat lower and are about 95 percent. In the polymerization of ethylene, as mentioned in Part I, small amounts (0.1 to 0.2 percent) of low-molecular waxes are obtained, and in the polymerization of propylene an atactic fraction amounts to 1 to 3 percent of the total yield. Many resin producers discard these materials. In our interviews one company mentioned that they sold the atactic fraction as an intermediate.

Considering all NP sources, the polymerization of ethylenes generates about 0.5 percent NP, whereas that generated in the polymerization of propylene can amount to 1.8 percent, on the average. The production of PVC usually generates more NP--average values are greater than 2 percent. This level is high, because the production of PVC often involves the preparation of a large number of grades, and thus requires many purging operations. For example, one producer lists about 2,000 different recipes for PVC compounds. They regularly sell about 150 compounds, and between 6 and 16 polymer grades. Normally, only about 20 grades of polyolefins are sold by a producer, but some sell as many as 100.

Resin producers try to limit their coloring operation. Many only add colorants to 5 to 10 percent of their production, and they usually sell high-volume products such as black and gray colored resins. Preparing many small lots of different colored resins is usually left to the outside processor. Resin producers turn to the outside processor for a number of reasons: (1) the independent processor can often provide specialized services and is able to do it more economically owing to proprietary know-how and equipment geared to small runs; (2) individual profit structures within large corporations favor outside purchase, if the price is right.

Most polyolefins require antioxidants, and this operation is an integral part of resin production. PVC is an exception; a large portion of this production is sold by the resin producer as polymer, and the compounding is carried out either by a compounder or fabricator. Because most compounding by the resin producer is done in-line with his polymerization operations, it is carried out on a large scale. Thus, NP levels are kept to a minimum, and we estimate that on the average about 0.2 percent NP is generated during this step.

NP can be generated even when the resin is prepared for shipment. Most resin is shipped in bulk by hopper car. When these cars are returned to the resin producer, invariably resin remains. As a minimum, 0.2 percent of the resin shipped out is returned as potential NP. In some instances, the customer returns cars with as much as 1,000 to 2,000 pounds of resin. This normally ends up with the off-grade resin. Depending upon each plant's operating procedures, the small amount of resin remaining in the car is either washed out with water and becomes NP, or it is blown out by forced air and put into a storage area for sale to a reprocessor. Oftentimes, in shipping less-than-carload quantities the bag filling operation generates NP. Again, the NP levels depend upon efficient operating procedures. Most polyethylenes are sold in bulk--from 50 to 75 percent and, in some instances, companies ship as much as 90 percent of their polyolefin by hopper car. In contrast, about 50 percent of the PVC produced is shipped in bulk.

Other sources for lesser amounts of NP include operations such as storage, and large scale testing in quality-control laboratories. From 0.05 to 0.1 percent NP can thus be generated. This NP is typically in the form of floor sweepings, powder, pellets, strands, and chunks.

As mentioned earlier, and as illustrated in the flow diagram (Figure 27), resin that is not within the specifications designated by the customer is usually sold as off-grade virgin material. About 50 percent of this is sold to a reprocessor; the remainder is sold to a fabricator who can use a lower-quality resin. The so-called transition material produced as the manufacturer changes his process from one grade to another, and excess resin left from filling a customer's order also is sold as off-grade resin. As mentioned earlier, about 10 percent of all resin production is sold as off-grade resin.

Most of the scrap plastic from the resin producer is in the form of strands and large chunks (some of these chunks can weigh as much as 100 pounds), and is generated by the purging operations during start-up. It is difficult to estimate the volume of scrap sold by the resin producer to the reprocessor. But, according to our survey, probably over 500 million pounds of scrap were sold by the resin producer in 1970 (Table 27). On the average, this amounts to 4 percent of the Big 5 resins.

The resin producer commonly grades his scrap according to color, melt index, density, and additive composition, and sells this scrap to a select number of reprocessors who, over the years, have become accustomed to working with the resin producer's scrap.

Characteristics of This Segment

The resin producer sells his product primarily to the fabricator, although small amounts, usually less than 10 percent, are sold to a compounder. If market conditions are such that the resin producer cannot sell all of his product, he stores it and attempts to sell it to the highest paying customer. In times of low demand (as mentioned in Part II), he often sells this surplus as off-grade resin. This procedure provides the resin

TABLE 27

ESTIMATED VOLUME OF SCRAP PLASTIC SOLD BY RESIN PRODUCERS (1970)*

Resin type	% SP (av.)	Wt SP (million lbs.)
Polyethylene	2.5	135
Polypropylene	4.0	45
Polystyrene	5.0	175
Polyvinylchloride	7.0	190
The Big 5 resins	4.0	545

*Source: Arthur D. Little, Inc.

producer with a safety valve that prevents the severe erosion of prime virgin resin prices. If the condition of oversupply continues, the resin producer sometimes stops production, and in a few cases this has occurred during the past year (1971), as resin producers closed manufacturing facilities. Alternatively, some resin producers ship this surplus resin to overseas locations as off-grade material.

The resin producer usually works very closely with the fabricator to meet his needs. If the demands of the market require the development of new resins with very specific physical properties, the resin producer will often set up an extensive R & D program. Resin manufacturers, in contrast to others in the plastics cycle, have many resources and, therefore, can engage in expensive support research. Generally, resin producers have large research organizations that can assist customers in solving their technical problems.

THE COMPOUNDER

As noted in the flow diagram for the resin producer, compounding is often carried out immediately after polymerization. But, compounding can be carried out by specialists who are known as compounders. Actually, most compounding in the plastics industry is done in the fabricator's facilities and, as mentioned previously, reprocessors also compound virgin resins.

Disposal of Scrap Plastic

The physical flow of material through the compounder's facilities is similar to that through the resin producer but, whenever possible, scrap plastic generated during compounding is recycled in the compounder's facilities rather than sold to an outside reprocessor (Figure 28). Scrap that is in the form of strands, drippings, and chunks, which cannot be recycled because it is severely contaminated, becomes NP.

We have not been able to estimate the volume of NP generated by the compounders specifically and have found it more convenient to consider the NP generated by the compounder and fabricator jointly. The first part of the flow diagram for the fabricator (Figure 29) is essentially identical to the one for the compounder, except that the fabricator sells some of his scrap plastic to a reprocessor. Although the flow diagrams indicate that adding additives such as lubricants, antioxidants, plasticizers, etc and adding colorants are separate operations, typically this is carried out as one operation. These functions have been separated on the diagram, because normally adding a colorant generates more NP than adding the usual polymer additives. For example, quantities of different colored scrap plastic from the coloring operation cannot be mixed easily in a reprocessing

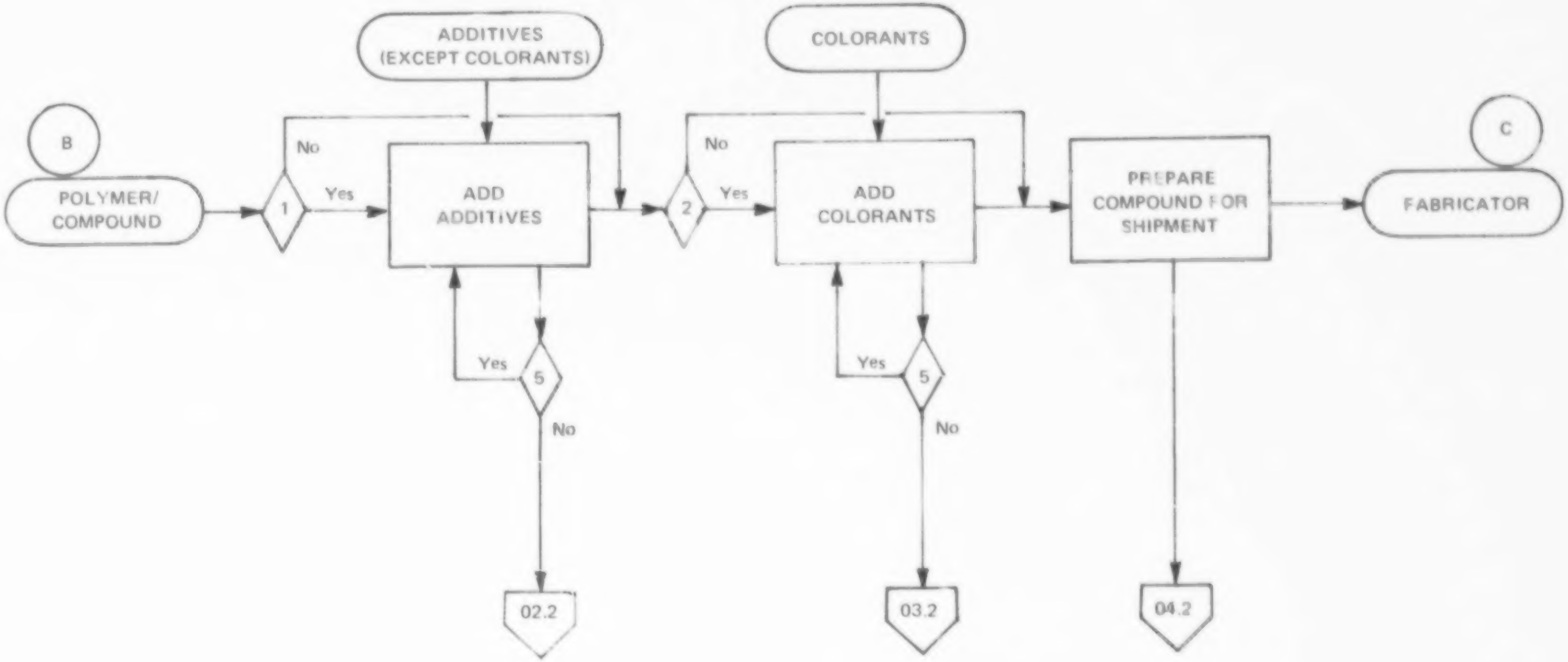

ADDITIVES (EXCEPT COLORANTS)
COLORANTS
B
POLYMER/ COMPOUND
1
No
Yes
ADD ADDITIVES
Yes
5
No
02.2
2
No
Yes
ADD COLORANTS
Yes
5
No
03.2
PREPARE COMPOUND FOR SHIPMENT
04.2
C
FABRICATOR

Figure 28. The compounder. Scrap plastic is usually recycled rather than sold to a reprocessor.

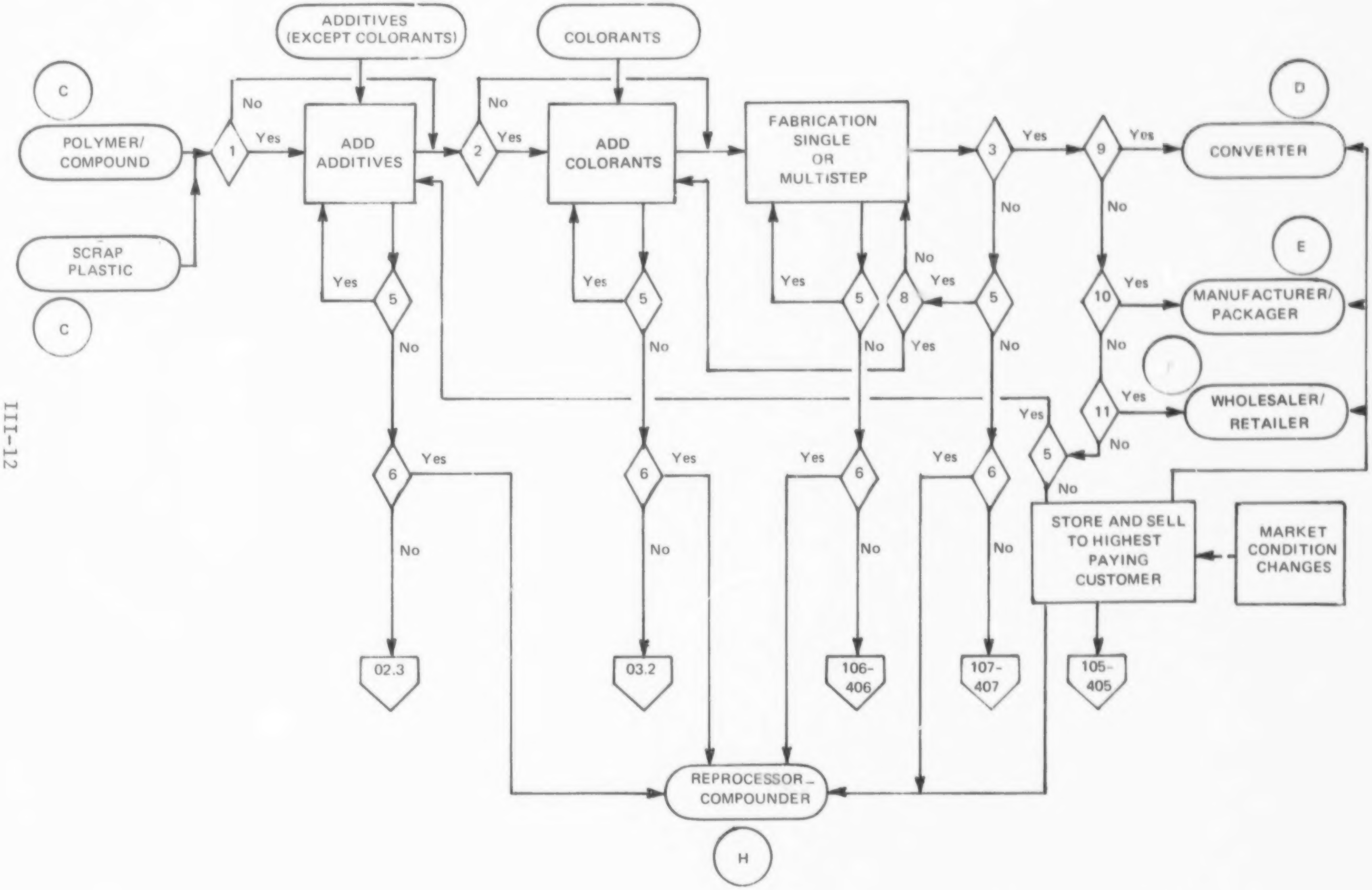

C
POLYMER/ COMPOUND
SCRAP PLASTIC
C
1
No
Yes
ADDITIVES (EXCEPT COLORANTS)
ADD ADDITIVES
5
Yes
No
6
Yes
No
02.3
2
No
Yes
COLORANTS
ADD COLORANTS
5
Yes
No
6
Yes
No
03.2
FABRICATION SINGLE OR MULTISTEP
5
Yes
No
6
Yes
No
106-406
8
No
Yes
Yes
3
Yes
No
5
Yes
No
6
Yes
No
107-407
9
Yes
No
D
CONVERTER
10
Yes
No
E
MANUFACTURER/ PACKAGER
11
Yes
No
WHOLESALER/ RETAILER
5
Yes
No
STORE AND SELL TO HIGHEST PAYING CUSTOMER
MARKET CONDITION CHANGES
105-405
REPROCESSOR_ COMPOUNDER
H

Figure 29. The Fabricator. Transforms polymer or compound (virgin or secondary) to a finished or semi-finished plastic article.

or a recycling operation; therefore, it becomes NP. Furthermore, as was mentioned in Part I, the preparation of color concentrates that are commonly used for coloring resins is normally a separate operation. About 90 percent of this color-concentrate business is done by the compounders, who sell the concentrate to fabricators and resin producers.

According to our interviews, NP generated by compounding in 1970, excluding the resin producer and reprocessor, amounted to approximately 60 million pounds (Table 28). Statistics related to the percent of resin production that is mixed with colorants were obtained from Modern Plastics,[5] and these values were used to determine the weight of NP generated by the coloring operation.

Most NP from the compounder would be difficult to recycle, because it is highly contaminated and is generated in small amounts in a number of scattered locations. Note from Table 28 that the major NP generated from compounding is PVC. About 60 percent of all manufacturers who compound use PVC as the raw material.[6] As mentioned earlier, the number of PVC compounds sold by the industry is extremely large.

Considering the volume of NP generated by all compounding (Tables 26 and 28), note that the percent NP based on total production ranges from a low of 0.2 percent, when the operation is carried out on a large scale by a resin producer, to over 1 percent when the operation is performed on a small scale by a compounder.

Characteristics of This Segment

About 30 companies today are involved primarily in compounding. Some are also jobbers; and some, as mentioned previously, are also reprocessors. We estimate that approximately 10 percent of the compounders do 80 percent of the business; thus, a few very large compounders do a major portion of the business.

Many who compound, whether they are solely compounders or fabricators, compound less than 1/2 million pounds per year. According to a recent survey,[6] about 35 percent of all processors belong to this category. Another 35 percent compound between 1/2 and 1 million pounds per year, and those compounding over 1 million pounds per year constitute 30 percent of all processors. Thus, because these compounding operations are usually small, opportunities for recycling the scrap are limited.

THE REPROCESSOR/COMPOUNDER

Because most reprocessors compound, the functions of reprocessing and compounding cannot be easily separated in discussing this segment.

TABLE 28

ESTIMATED VOLUME OF NUISANCE PLASTICS GENERATED BY COMPOUNDING, 1970*
(Excluding Resin Producer and Reprocessor)

Code no.	Type resin	Operation	% resin production affected†	Wt. resin affected, MM lb.	AV. % NP	Total NP, MM lb.
02.2,02.31	HDPE	Add additives	80	1360	0.3	
02.2,02.32	LDPE	(other than	50	2650	0.3	
02.2,02.33	PP	colorants)	80	808	0.3	
02.2,02.34	PS ‡		60	2010	0.3	
02.2,02.35	PVC		90	2835	0.6	
03.2,03.31	HDPE	Add colorants	65	1055	0.3	
03.2,03.32	LDPE		30	1255	0.3	
03.2,03.33	PP		75	740	0.3	
03.2,03.34	PS		60	1990	0.3	
03.2,03.35	PVC		75	2290	0.3	
Total						

* Source: A.D. Little, Inc.

† Estimates by A.D. Little, Inc., and Modern Plastics, 47(12): 44, Dec. 1970

‡ All styrene polymers including ABS.

Raw Material Supply

The reprocessor/compounder usually uses both scrap plastic and virgin polymer or compound as raw material (Figure 30). The latter is often off-grade material, and scrap is frequently mixed with off-grade resin to produce the finished compound. As mentioned previously, approximately 50 percent of the off-grade resin produced by the resin producer (5 percent of the total resin production) goes to the reprocessor. Over the years, the reprocessor has been handling less off-grade resin, as the resin producer has found his own market for this product.

Most scrap plastic used by the reprocessor also comes from the resin producer; a small portion comes from the fabricator, and an even smaller amount from the converter. Estimates of the total weight of scrap plastic reprocessed by the reprocessor are difficult to make, because the resin producer usually lumps off-grade resin together with scrap plastic when he sells to the reprocessor. Based on our interviews with the resin producer and our estimates, the volume of scrap plastic reprocessed by the reprocessor approached 1 billion pounds in 1970 (Table 29). Again, PVC scrap predominates, because PVC compounds vary and are more difficult to process.

A reprocessor/compounder generates sizable quantities of NP. First, as the flow diagram shows (Figure 30), he often segregates his raw material, usually by hand picking, to remove grossly contaminated stock. Depending upon the extent of contamination in the scrap, the overall average percent NP can vary from 4 to 6 percent (Table 29).

Characteristics of This Segment

Most reprocessors have a limited technical staff, although they have become more sophisticated in recent years. Reprocessors require some technical service facilities for incoming scrap is usually examined and tested before it is purchased. Typically, the scrap is tested for melt index and density because, to be successful, the reprocessor must convince the fabricator that his product can be used effectively in the fabricator's operation. The fabricator usually is unwilling to take risks with reprocessed stock.

The reprocessor normally locates close to his customers (within a 150 mile range). Most reprocessor/compounders are represented by small companies. Geographically, they are concentrated in the major population cities along the East Coast, and in Ohio. A number are also located in the Chicago and Los Angeles areas, and a few in Texas.

One of the major impediments to recycling is the absence of major markets for the recycled plastic (see Part V); therefore, the reprocessor

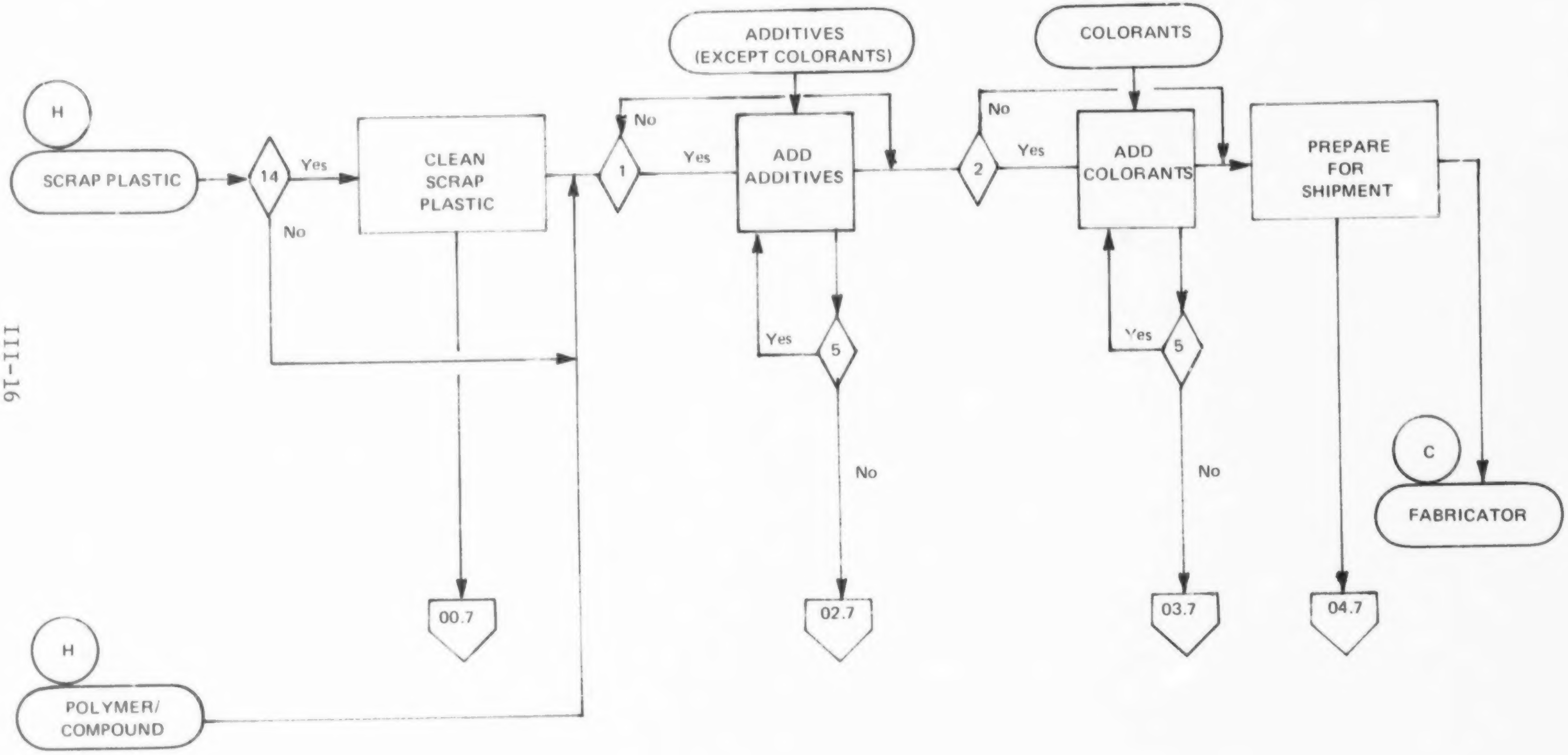

H
SCRAP PLASTIC
14
Yes
No
CLEAN SCRAP PLASTIC
00.7
H
POLYMER/ COMPOUND
1
No
Yes
ADDITIVES (EXCEPT COLORANTS)
ADD ADDITIVES
Yes
5
No
02.7
2
No
Yes
COLORANTS
ADD COLORANTS
Yes
5
No
03.7
PREPARE FOR SHIPMENT
04.7
C
FABRICATOR

Figure 30. The Reprocessor. The reprocessor/compounder usually uses both scrap plastic and virgin resin as raw material.

TABLE 29

ESTIMATED VOLUME OF NUISANCE PLASTICS GENERATED BY REPROCESSOR/COMPOUNDER*

Code no.	Type resin	Wt. (MM lb.) SP reprocessed	AV. % NP	Total NP (MM lb.)
00,02-04.71	HDPE	65	4	3
00,02-04.72	LDPE	175	4	10
00,02-04.73	PP	60	5	20
00,02-04.74	PS†	250	4	2
00,02-04.75	PVC	330	6	8
Total		880	5	

* Source: A.D. Little, Inc.

† All styrene polymers, including ABS.

often spends much of his time developing markets for his reprocessed material. This is an important and major task for the reprocessor and is, no doubt, the cause of his secrecy, for he must protect his marketing information. Once the markets have been developed, the reprocessors usually prepare their reprocessed material to meet the specifications of their customers. Accordingly, many reprocessors have long-term contracts to take scrap from certain fabricators and resin producers. This provides the reprocessor with a somewhat basic feedstock that can be reprocessed for established end uses. Often the color of the available scrap is least important, for in reprocessing such scrap, it is tinted a dark color to mask color variations.

In addition to selling secondary resin as a commodity, reprocessors often assist fabricators by reprocessing their fabricator's scrap and charging him a service fee. In this case, the scrap is segregated and treated separately by the reprocessor, and it is returned to the fabricator as a secondary resin of known, rather than unknown, quality. Various compounds are often handled in this manner.

As another service, a reprocessor will sometimes collect different colored plastic scrap (especially vinyl sheet) from a fabricator, sort it according to its color, and then resell it to the original fabricator.

THE FABRICATOR

A fabricator can be viewed as the man in the middle. He works closely with both the end-product company or manufacturer/packager and the resin producer. Following the flow diagram (Figure 29) the fabricator transforms polymer or compound (virgin or secondary) to a finished or semi-finished plastic article. Note that in some instances the converter's scrap plastic can be used as feedstock. This will be discussed in the next section.

Disposal of Scrap Plastic

Recycling by the fabricator is extensive, as was noted in Part I. On the average, fabricators usually recycle between 10 and 15 percent of the resin that they use. This amounted to more than 1-1/2 billion pounds of scrap plastic in 1970. Scrap from fabrication and compounding operations that is not easily recycled by the fabricator is sold to the reprocessor or disposed of as NP. The disposal pattern is similar to that described for the resin producer.

The following are specific examples of the way in which scrap plastic is disposed of in a fabricator's operation. One fabricator, who sells

PVC film, generates about 25 percent scrap in his operation. Most of this is recycled in his own facilities, 4 to 8 percent is sold to a reprocessor, and about 1 percent becomes NP. The material shipped to the reprocessor is usually in the form of baled film scrap and chunks of plastic from the baled scrap and chunks of plastic from the extruder.

In another example, where the fabricator makes polypropylene film, between 30 and 40 percent of his raw material supply becomes scrap plastic. Only about 15 percent can be recycled in this fabricator's operation without reducing the quality of his product; the remainder is sold to reprocessors. The best scrap--about 25 percent of his production--is often repelletized, and the remainder (as much as 10 percent) is baled as film.

To cite still another example, consider the case of a fabricator who makes PVC bottles for a food application. Great care has to be taken in the production of these bottles so that good color and clarity are maintained; therefore, in these applications little scrap can be recycled. In one example, the scrap plastic generated during the fabrication step amounted to about 35 percent of production. This was disposed of as follows: 20 percent was used to fabricate bottles for non-food applications; 7 percent was sold to another fabricator; 3 percent went to a reprocessor; and the more contaminated scrap (about 5 percent) became NP.

The amount of nuisance plastics generated by the fabricator varies with each fabrication process (Table 30). The amount generated depends on the volume of resin used in the particular fabrication process and the average percent NP generated. Not surprisingly, most of the NP from fabrication arises from injection molding. Injection molding is the major fabricating process, and the levels of NP can range from 1 1/2 to 3 percent (Table 31). Many small molding shops use a variety of colored resin stocks; as a result, NP levels are high. Wire and cable extrusion is another major process that generates a large amount of NP. Average NP levels vary from 4 to 5 percent, and the total amounts to 46 million pounds of NP. Film and sheet extrusion, which is the second fabrication process in production volume, generates a relatively small amount of NP because film scrap is easily recycled (see Part I). In contrast, the extrusion-coating process, which produces composite scrap such as polyethylene or paperboard, generates high levels of NP (6 percent). The manufacture of articles made from foamed plastic also generates very high levels of NP (ca 9 percent).

Over 300 million pounds of NP were generated by the fabricator in 1970 in processing 11.9 billion pounds of resin. This amounts to an average of 2.7 weight percent NP based on production (Table 31).

Characteristics of This Segment

The nature of the operation beyond the fabrication step varies with the particular fabrication process. Let us consider some of the major ones.

TABLE 30

SUMMARY OF THE ESTIMATED VOLUME OF NP GENERATED BY THE FABRICATOR* (1970)

Process	Total production, million lb.	Total NP, million lb.
Blowmolding	1200	17
Injection molding	3475	70
Extrusion-film and sheet	2400	27
Extrusion coating	450	27
Extrusion-wire and cable	880	46
Extrusion-profile and pipe	1385	30
Coextrusion	110	10
Calendering	685	7
Calender coating	400	28
Coating	325	26
Compression molding	140	3
Slush molding	110	3
Rotomolding	90	3
Foam processing	250	22
Total	11,900	319

* Source: A. D. Little, Inc.

TABLE 31

ESTIMATED VOLUME OF NUISANCE PLASTICS GENERATED BY FABRICATION, 1970*

Code No.	Type resin	Process	Production, MM lb.	AV. % NP	Total NP MM lb.
105,106,107.31	HDPE	Blow molding	720	1.2	8.6
105,106,107.32	LDPE		60	1.0	0.6
105,106,107.33	PP		110	1.2	1.3
105,106,107.34	PS†		250	1.2	3.0
105,106,107.35	PVC		65	5.0	3.2
115,116,117.31	HDPE	Injection molding	375	2.0	7.5
115,116,117.32	LDPE		620	1.5	9.3
115,116,117.33	PP		600	2.0	12.0
115,116,117.34	PS		1500	2.0	30.0
115,116,117.35	PVC		380	3.0	11.4
125,126,127.31	HDPE	Extrusion, film, and sheet	75	1.2	0.8
125,126,127.32	LDPE		1960	1.2	23.5
125,126,127.33	PP		75	1.2	0.8
125,126,127.34	PS		15	1.2	0.2
125,126,127.35	PVC		175	1.2	2.1
135,136,137.31	HDPE	Extrusion coating	15	6.0	0.9
135,136,137.32	LDPE		430	6.0	25.8
135,136,137.33	PP		5	6.0	0.3
145,146,147.31	HDPE	Extrusion, wire and cable	40	5.0	8.0
145,146,147.32	LDPE		415	5.0	20.8
145,146,147.33	PP		8	5.0	0.4
145,146,147.35	PVC		415	4.0	16.8
155,156,157.31	HDPE	Extrusion profile and pipe	90	1.0	0.9
155,156,157.32	LDPE		65	1.0	0.6
155,156,157.33	PP		25	1.0	0.2
155,156,157.34	PS		775	2.0	15.5
155,156,157.35	PVC		430	3.0	12.9
165,166,167.32	LDPE	Coextrusion	85	9.0	7.6
165,166,167.33	PP		25	9.0	2.2
175,176,177.35	PVC	Calendering	685	1.0	6.8
185,186,187.35	PVC	Calender coating	400	7.0	28.0
195,196,197.34	PS	Coating	310	8.0	24.8
195,196,197.35	PVC		15	8.0	1.2
205,206,207.35	PVC	Compression molding	140	2.0	2.8
215,216,217.35	PVC	Slush molding	110	3.0	3.3
225,226,227.31	HDPE	Rotomolding	35	3.0	1.0
225,226,227.32	LDPE		55	3.0	1.6
235,236,237.34	PS	Foam processing	250	9.0	22.5

* Source: A. D. Little, Inc.

† All styrene polymers, including ABS

Injection Molding. Injection molded goods do not normally go to a converter; most go to a manufacturer. Often the fabricator himself is the manufacturer, as in the fabrication of household and sporting goods. Some of the automobile manufacturers also mold their own parts. These fabricator-manufacturers then typically sell their products to a distributor or wholesaler.

A large fabricator can request the resin producer to make a particular resin to his own specifications, if warranted by the potential market; normally, the small molders only can select from a portfolio of molding resins made available by the resin producer. This is true for fabricators in general, whether they are injection molders, film extruders, or blow molders.

Normally, most large manufacturers, such as those in the automobile and appliance industries, set specifications that must be met by the molder. If the molded part does not meet the customer's specifications and is rejected, it often is granulated, remelted, and reformed. However, colored reject parts can be a problem, unless the fabricator sells black or dark colored molded goods. If the rejected product is contaminated or is part of the manufacturer's composite product, salvage is usually impossible.

Film Extrusion. Most film is further processed by the converter. Approximately 85 percent of all polyethylene film but only 10 percent of the PVC film goes this route. A major portion of the PVC film is sold directly to the supermarket for meat and produce wrapping. In this case, the supermarket also is the packager. Film that goes directly to a packager is often used to wrap toys, toilet articles, household goods, etc. Film used for construction and agricultural applications normally goes to a distributor or wholesaler.

In most cases the film fabricator sets specifications for the resins he uses. These specifications include: melt flow, color, particle size, and the appropriate additives. In turn, the film producer sells his product according to gauge, optical properties, slip properties, printing receptivity, and shrink properties. The less sophisticated film purchaser usually monitors his purchases simply by performance.

The film market is gradually becoming more complex and the number of products is continuously increasing. Many film producers today manufacture more than 20 grades of film based on one resin type. Overall, the film market is a price/delivery market and not particularly a price-conscious one. Furthermore, the geographic location of the film fabrication facility with respect to both raw materials and markets is not very critical.

The film fabricator has little difficulty in recycling products that do not meet specifications. However, once a converter prints on film, difficulties can arise. In recycling, printing not only causes color problems, but the degradative effect of the components in the ink itself and, in particular, the presence of solvents makes printed scrap essentially worthless for most film applications. However, the growing market for polyethylene trash bags, which are often colored, may open a new market for this printed-film scrap. Unfortunately, most printed-film scrap today ends up as NP, for very few reprocessors want it; however, the reprocessor does buy clear reject film.

Blow Molding. In the case of blow-molded articles, most are sold to a packager. A small number may go to a converter, where they are decorated (printed, labeled, etc), but more often the decoration, particularly of bottles, is done by the packager. The packager in this case is both packager and converter. If the economics are right, the fabricator sometimes decorates in line with his fabrication operation; most embossing of bottles is done by the fabricator.

The bottle fabricator usually buys his resins according to the following specifications: melt index, density, stress-crack resistance, antioxidant content, color, odor, contamination, particle size, mechanical properties, electrical properties, and moisture content. Fabricators also specify any special additives that may be required. Even though the fabricator may set the final specifications for the resin, he obviously does so by considering the packager, whose performance requirements must be met. Large packagers will often develop new bottle designs that include the resin specifications. These packagers then obtain bids from various fabricators to manufacture these new bottles according to their specifications.

Because of the inefficiency of shipping empty containers, blow molding tends to be a regional business with one plant serving customers within a 100 to 300 mile radius. When the fabricator's customer rejects a shipment of bottles, it is usually because of a finish problem; therefore, the bottles are easily salvaged. If the fabricator has appropriate equipment, rejects can be reground and recycled in his production line. However, if the fabricator believes that the bottles can be used for other applications, he sometimes stores them in his warehouse and sells them when he can. Bottles that have been labeled by the fabricator's customer are normally very difficult to recycle, and they frequently end up as NP.

Warehousing is a major factor in the manufacture of plastic bottles. Typically, each plant has a warehouse that is about three times the size of the manufacturing facility. Occasionally, the fabricator makes room in his warehouse by having a ''fire sale,'' when he sells his odd lots of bottles.

Research and Development. In recent years there has been an increasing pressure on the fabricator to deepen his involvement in R & D. As new highly engineered applications for plastics have developed, and more and more stringent standards have been developed by government agencies in the interest of public safety, the end user or manufacturer/packager has forced the fabricator to mold parts to his rigid specifications. This has forced the fabricator to increase his testing capability to determine if his finished parts are satisfactory. At the same time, resin producers are beginning to play a less critical role in product development. Furthermore, the trend toward proprietary product lines on the part of some fabricators is also leading to more R & D activity by the fabricator. Thus, the fabricator is becoming increasingly more involved in materials testing, seeking to find the best material for a given application, and in determining if his raw materials and the products he makes are within specified tolerances.

Yet, despite this movement into R & D, many fabricators continue to rely on the R & D services provided by resin producers. Occasionally, resin producers will enter into a product development project with the fabricator, but they have never involved themselves extensively in this approach. The end-user or the end-user/fabricator is in a much better position to get product development aid from a resin producer, particularly when the application is new to plastics and has a large potential for resin consumption.

This increased involvement in research by the fabricator portends changes in the structure of the industry. The major effect will probably be an acceleration of the current trend toward specialization by fabricators, as they respond to the demand for increased technical expertise.

THE CONVERTER

The converter who transforms a fabricated item to a finished plastic product, can generate very large volumes of scrap plastic and NP. However, if the converting operation is carried out in line or adjacent to the related fabrication process, much of the scrap plastic can be salvaged by being recycled in the fabrication operation.

Disposal of Scrap Plastic

The converter can recycle only to a very limited extent (Figure 31). For example, in decorating three-dimensional products such as bottles, they are sometimes mislabeled. Occasionally, these bottles are salvaged by removing the labels and then rerouting the bottles to the printing lines. This is only done when technically possible and when the economics are right; if not, the mislabeled bottles become NP.

To take another example, scrap plastic is generated during thermoforming (see Part I) and as much as 20 to 80 percent scrap can be generated in trimming thermoformed objects such as ''blister packs'' or moldings for automobiles. If the converter is also a sheet fabricator, then there is little difficulty in recycling this scrap. On the other hand, converters who do not have this advantage must recover some value for the scrap to operate profitably. Under these circumstances, the converter commonly ships the scrap from his finishing operation to his sheet fabricator, who is usually within 300 to 500 miles.

In converting operations such as decorating and sealing of film, little scrap can be recycled by the converter, unless, as mentioned above, converting and fabrication are carried out together. In our interviews, only a few examples were noted where the converter was able to sell some of his scrap film to his fabricator supplier. In any case, printed film, as was noted in the previous section, is difficult to recycle; most ends up as NP. Usuaully, reject articles also end up as NP, although rejected unprinted plastic bags are sometimes sold to a reprocessor (Figure 31).

If the converting operation involves cutting and trimming of coated paperboard or paper, as in the manufacture of plastic-coated milk cartons and cups, none can be recycled in the converter's operation. However, because this scrap is valuable, the converter often sells his scrap through a jobber or directly to a reprocessor who can recover the high-quality pulp from the scrap material. About 80 percent of this coated scrap from both the converter and fabricator is being recycled in this manner. But today none of the plastic is recovered from the coating. These plastic-coated products contain 8 to 12 percent polyethylene. See Part IV for further details about the recovery of this coated scrap.

A major source of NP from cutting is that derived from PVC-coated fabrics that are used as upholstery covering. None of this composite scrap is being recycled today. The possibilities of recovering this PVC are discussed in Part IV.

Using average values for the percent NP generated by each converting operation, we estimated the NP according to resin type (Table 32). Cutting of PVC-coated fabrics, for example, generates anywhere from 8 to 20 percent NP. We assumed an average value of 12 percent in computing the volume of NP from this source. The estimates in Table 32 also take into account that only a certain percentage of all fabricated goods go through the converting operations. For example, about 50 percent of all polyethylene film is printed. In total, about 5.4 billion pounds of the 11.9 billion pounds that were fabricated were converted in 1970 (Table 33). Converting generated 260 million pounds of NP, while fabricating generated 319 million pounds. This represents an overall average NP value of 4.8 percent for converting as compared to 2.7 percent for fabricating. Thus, the converter contributes more than his share to the total NP produced during the manufacture of plastic products. Note also that the major source of NP from the converter is that from cutting and trimming operations (Table 33).

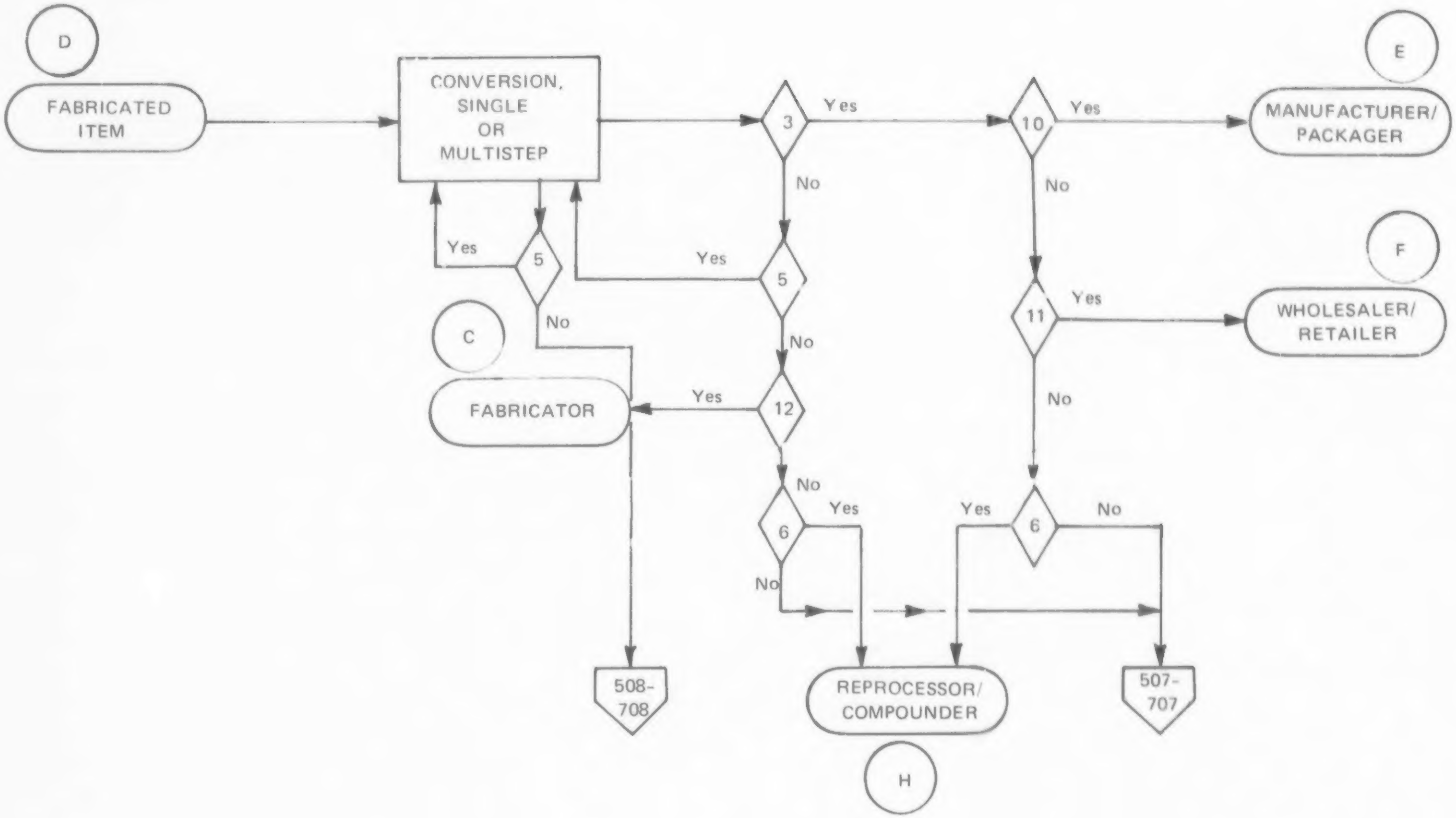

D
FABRICATED ITEM
CONVERSION, SINGLE OR MULTISTEP
3
Yes
No
10
Yes
No
E
MANUFACTURER/ PACKAGER
5
Yes
No
C
FABRICATOR
5
Yes
No
12
Yes
No
11
Yes
No
F
WHOLESALER/ RETAILER
6
Yes
No
6
Yes
No
508-708
REPROCESSOR/ COMPOUNDER
H
507-707

Figure 31. The converter. The converter can recycle only to a very limited extent.

TABLE 32

ESTIMATED VOLUME OF NP GENERATED BY THE CONVERTER (1970)[*]

Code no.	Type resin	Operation	Production affected MM lb.	AV % NP	Total NP, MM lb.
507,508.41	HDPE	Decorating 3-dimensional products	520	0.3	1.6
507,508.42	LDPE		40	0.3	0.1
507,508.44	PS[†]		140	0.3	0.4
507,508.45	PVC		50	0.3	0.2
517,518.42	LDPE	Decorating film	830	4	33.2
517,518.43	PP		80	4	3.2
527,528.42	LDPE	Sealing printed bags[‡]	830	3	24.9
527,528.43	PP		80	3	2.4
537,538.42	LDPE	Sealing unprinted bags	700	5	35.0
537,538.43	PP		20	5	1.0
537,538.45	PVC		25	5	1.2
547,548.41	HDPE	Cutting	15	10	1.5
547,548.42	LDPE		430	10	43.0
547,548.43	PP		5	10	0.5
547,548.45	PVC		700	12	84.0
557,558.41	HDPE	Thermoforming	75	3	2.2
557,558.42	LDPE		150	3	4.4
557,558.43	PP		100	3	3.0
557,558.44	PS		550	3	16.5
557,558.45	PVC		80	3	2.4
Total			5420	4.8	260.7

[*] Source A. D. Little, Inc.

[†] All styrene polymers, including ABS.

[‡] Printing not included.

TABLE 33

SUMMARY OF THE ESTIMATED VOLUME OF NP GENERATED BY THE CONVERTER (1970)*

Process	Production MM lb.	Total NP MM lb.
Decorating 3-dimensionals	750	2.3
Decorating film	910	36.4
Sealing	1655	64.5
Cutting	1150	129.0
Thermoforming	955	28.5
Total	5420	260.7

* Source: A. D. Little, Inc.

NP derived from plastic-bag making is the next largest category, because the production volume of this product is relatively high.

Characteristics of This Segment

The converter works closely with the fabricator to see that his material specifications are met. In the case of plastic film, the converter's major interest is in the film's heat sealability and ink receptiveness. The converter's customers, on the other hand, are mainly interested in the appearance and performance of the finished goods.

The major outlets for the converter's products are the manufacturer/packager and the wholesaler/retailer. Most plastic bags, for example, are sold to packagers for their filling operations, but bags are also sold directly to retail outlets such as supermarkets. PVC-coated fabrics used in the upholstery applications are normally sold to a manufacturer. Little goes via the wholesaler/retailer channel.

As the form-fill-seal and fill-seal operations become more extensive, which is our expectation, more packagers will become converter/packagers. Most of this new activity will arise from new business opportunities, rather than at the expense of the present converter.

THE MANUFACTURER/PACKAGER

This segment of the plastics cycle includes a very large number of companies, ranging widely in size, and employing as few as two or three, or as many as thousands. Geographically, these companies are concentrated near the metropolitan centers.

Disposal of Scrap Plastic

The values of NP generated [illegible] this segment as well as those already discussed are based on production statistics (Table 34). However, the manufacturer/packager usually receives a completely finished plastic articles, therefore, most NP generated by this segment is different from that described above but is similar to that generated by the wholesaler/retailer or customer, who also receive finished goods. These segments thus generate product NP rather than process NP. We estimate that process NP amounted to 885 million pounds in 1970, as indicated in the flow diagram (Figure 32).

To simplify computations, disposable products such as packaging, which become NP within a year or less, are included with the NP generated

TABLE 34

ESTIMATED VOLUME OF NP GENERATED BY THE MANUFACTURER/PACKAGER AND DISTRIBUTOR (1970)*

Code no.	Type resin	Operation	Production affected MM lb.	AV % NP	Total NP, MM lb.
(1)9.51-(16)9.51,(1)7.51(16)7.51	HDPE	Assembling, packaging	810	0.7	5.7
(1)9.51-(16)9.51,(1)7.51(16)7.52	LDPE		1905	0.7	13.3
(1)9.51-(16)9.51,(1)7.51(16)7.53	PP		830	0.7	5.8
(1)9.51-(16)9.51,(1)7.51(16)7.54	PS†		2875	0.7	21.1
(1)9.51-(16)9.51,(1)7.51(16)7.55	PVC		2810	0.7	19.6
(1)4.61-(16)4.61,(1)5.61-(16)5.61	HDPE	Storing distributing displaying	810	0.5	4.0
(1)4.61-(16)4.61,(1)5.61-(16)5.62	LDPE		1905	0.5	9.5
(1)4.61-(16)4.61,(1)5.61-(16)5.63	PP		830	0.5	4.2
(1)4.61-(16)4.61,(1)5.61-(16)5.64	PS		2875	0.5	14.4
(1)4.61-(16)4.61,(1)5.61-(16)5.65	PVC		2810	0.5	14.0
Total					111.6

* Source: A. D. Little, Inc.

† All styrene polymers, including ABS

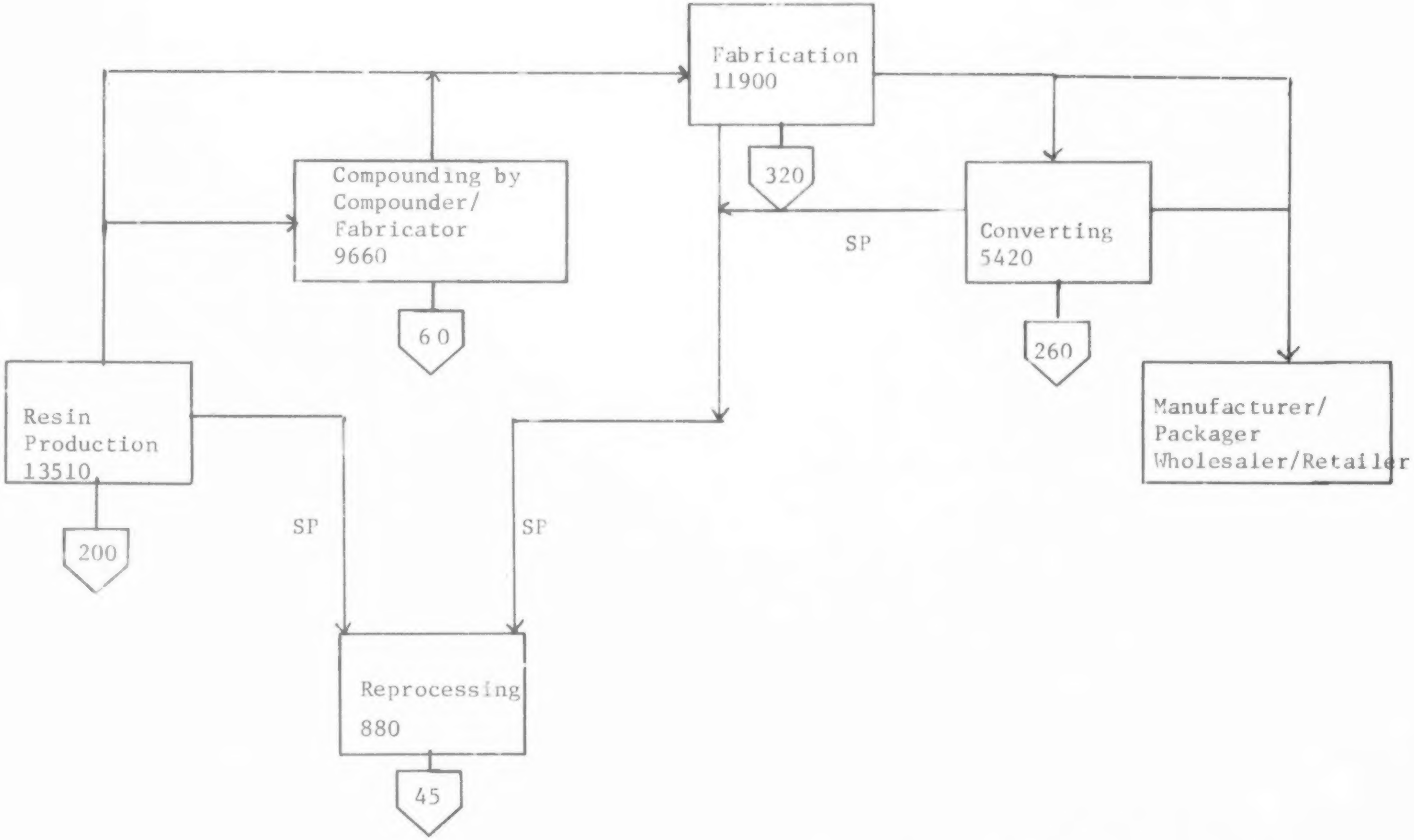

Fabrication
11900
Compounding by
Compounder/
Fabricator
9660
320
SP
Converting
5420
60
260
Resin
Production
13510
Manufacturer/
Packager
Wholesaler/Retailer
200
SP
SP
Reprocessing
880
45

Figure 32. Generation of industrial NP in the Plastics Cycle. Units are in MM lb.

by the consumer (see section ''The Consumer''). Thus, we avoid the risk of double counting the packaging NP. Accordingly, the production statistics in Table 34 were computed by subtracting the volume of resin used for the manufacture of packaging products from the total volume of resin produced in 1970.

The amount of NP generated by assembling and packaging plastic products vary considerably with the type product and the company. We assumed an average value of 0.7 percent of production in our computations, which amounted to a total of approximately 65 million pounds of NP from these sources. Although NP from assembling and packaging of products using plastic packaging was not considered in these computations, it is interesting to note that 5 to 7 percent of the film used in many of the wrapping operations in industry is discarded as NP by the manufacturer/packager. About 0.5 percent NP is generated during most filling operations, and in many instances larger amounts are generated. This packaging NP is considered consumer NP in this report.

NP from the manufacturer/packager segment, in contrast to that from others mentioned up to this point, is contaminated with quantities of non-plastic refuse such as paper, metal, etc. Most manufacturer/packagers use a number of materials, and a percentage of these also enter the waste stream. Scrap generated by the manufacturer/packager is seldom sold to a reprocessor and, as shown in the flow diagram (Figure 32), reject goods also become NP.

Characteristics of This Segment

The manufacturer/packager is a key decision maker in the life cycle of any plastic item. He is close to the consumer and is very sensitive to his needs. The very large companies, as mentioned above, often design the product, whether it is a package or a plastic part of an appliance or an automobile. Having this design, the large manufacturer/packager then meets with the fabricator to determine how the end item can best be made, considering the limitations of the existing plastic materials. The smaller companies in this segment, however, are not in this position. They usually take advantage of what is made available to them from fabricators and converters. Thus, among the packagers, it is the large companies who are the pace setters, who decide how a product is sold--whether in a plastic bottle, a coated-paperboard carton, a plastic pouch, or a completely non-plastic container.

The manufacturer/packager locates his plant close to his market, and when he sells a product such as bleach, detergents, and various food products, he also determines the location of the bottle fabricator's plant, for it has to be within a few hundred miles of the packager.

Many of the large manufacturer/packagers use consumer panels and elaborate testing to determine what the consumer wants, and how he makes his choice. In the case of packagers, the major ones are usually familiar with the problems of the supermarket; therefore, they go directly to the housewife when they develop a new package. For example, if they are considering two different ways of packaging an end item, they will sample the community and test the consumer response. The package-design group works very closely with those in consumer research to develop the most effective package that meets the technical requirements, the limitations of costs, and the needs of the consumer. Each packager also recognizes that the package today must not only contain the product well, but it has to sell the product as it is displayed on the shelf. The word ''eye appeal'' describes this concept, and the package designer knows its importance.

Most packagers are supplied by a number of fabricators. For example, a large packager who sells bleach may use between 10 and 12 different bottle fabricators. The packager works closely with the fabricator as he continuously searches for the package that performs best at the cheapest price. Specifications by the manufacturer/packager are usually set on a performance basis. If a fabricator is interested in introducing a new material, it is he who takes the initiative to interest the packager. Some of the factors considered by the manufacturer/packager in selecting a fabricator are adequate technical service, a good supporting research effort, and short shipping distances.

Many packagers are also converters. For example, they label plastic bottles, seal plastic bags, etc. The generation of nuisance plastic by these processes already has been described. NP generated solely by the manufacturer/packager operation is produced mainly during the assembling and packaging of the product.

Flow of Products From This Segment

As the flow diagram (Figure 33) illustrates, the manufacturer/packager can distribute his product in three different ways: (1) to the wholesaler; (2) directly to the retailer; (3) to the consumer. The first way is the most common. To illustrate these three paths, let us consider the very diversified food industries who use plastic packaging extensively. The overwhelming majority of the companies in these industries are single-plant operations, and the approximately 25,000 food processors now produce over $100 billion worth of products annually.

The following types of products packaged in plastics move from the packager to the wholesaler of food and related products: bleach, detergents, toiletries, candy, frozen food, cake mixes, paper products, margarine, edible oils, processed meats, and cheese. A significant amount of potatoes, apples, etc are packaged in polyethylene bags. These are packaged by

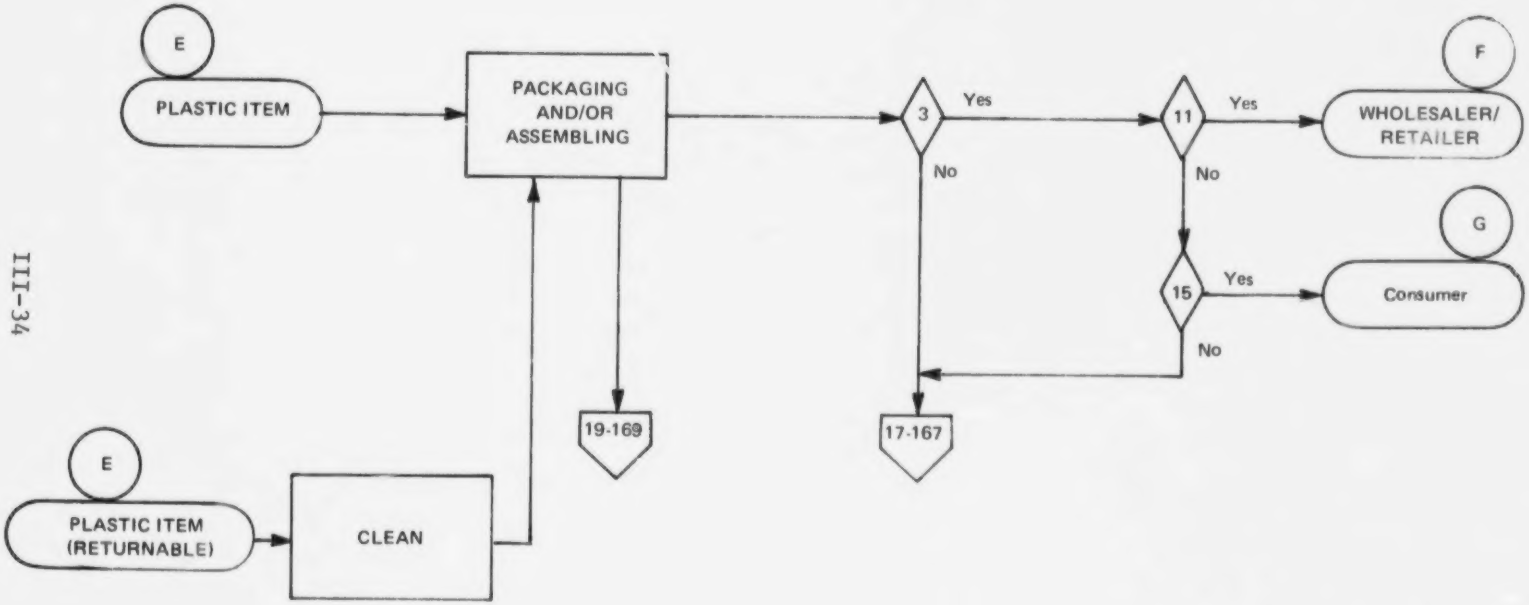

E
PLASTIC ITEM
PACKAGING AND/OR ASSEMBLING
3
Yes
No
11
Yes
No
F
WHOLESALER/ RETAILER
G
15
Yes
No
Consumer
19-169
17-167
E
PLASTIC ITEM (RETURNABLE)
CLEAN

Figure 33. The manufacturer/packager. The manufacturer/packager usually use a number of materials; thus, the scrap is contaminated with quantities of non-plastic refuse.

numerous small repackers located in the metropolitan areas near the retailer. In packaging candy, manufacturers generally use roll film stock in vertical form-fill-seal equipment; in this case they have taken on the role of the converter. The so-called ‘‘portion packs,’’ which are often used for packaging jellies and jams, etc, are also sold through special distributors to the hotel, restaurant, and institutional consumer.

The following products that are packaged in plastics are distributed directly to the retailer by the packager. Bread is generally baked and packaged locally on fully automatic machines using preformed bags and delivered directly to the retail stores by the baker's own delivery men who also stock the shelves. Most crackers and cookies are delivered in a similar manner; an increasing number of these products will be packaged in recloseable polyethylene bags in the future. Dairies deliver milk directly to the supermarket or grocery retailer. Most milk is packaged in polyethylene-coated paperboard (Pure Pak) containers. The dairies purchase flat blanks from the converters, form them into containers, and fill and seal them. Other dairy products, such as cottage cheese, sour cream, yogurt, etc that are packaged in pre-formed impact-polystyrene cups, are filled by the dairies and delivered to the retailer. Eggs that are packed in thermoformed foamed polystyrene cartons are packed by local packers, who are usually located near the farm areas. These eggs are also shipped directly to retailers. Snack foods, such as potato and corn chips, are packaged in pouches made from a glassine/polyvinylidene chloride/oriented-polypropylene laminate. The packager normally uses form-fill-seal equipment, and the filled pouches are delivered to the retailer by the shipper delivery salesmen.

The best example of distribution from the packager directly to the consumer is the delivery of milk and other dairy products to the home and to the hotel, restaurant, and institutional consumers, such as hospitals, schools, etc.

THE WHOLESALER/RETAILER

Most companies in this segment are located in the population centers that they serve. In New York City, for example, there are over 3,000 wholesale establishments that deal primarily with groceries and related products.[7] Most of these have fewer than 20 employees. These wholesalers, in turn, serve approximately 17,000 retail establishments in the city. While the largest percent of these outlets are small neighborhood stores, 30 major chain stores dominate the New York City area.[8]

Disposal of Scrap Plastic

The wholesaler's major function is to purchase products in large quantities from the manufacturer, warehouse them, and prepare small, usually mixed, orders of products for shipment to the nearest retail outlets. As shown in the flow diagram (Figure 34), the retailer then uncrates his shipment and, where required, stocks his shelves. All of these operations of storing, preparing for shipment, shipping, uncrating, stocking on shelves, etc, generate NP. The NP from this segment, in contrast to that from the fabricators and converters, is diluted by other material wastes that are generated by the wholesaler/retailer. Thus, it resembles the NP from the manufacturer/packager. Again, packaging wastes were excluded in computing the NP generated by these operations (Table 34).

A typical supermarket uses about 2800 lbs of PVC film and 2000 lbs of foamed polystyrene per year for meat and produce wrapping. The supermarket also often buys clear polystyrene trays, and polyethylene bags. These stores regularly re-wrap a portion of their meat and produce, which generates between 5 and 7 percent NP (included with consumer NP). An average supermarket, which sells about $2 million worth of products per year, generates approximately 3 tons of dry refuse each week. Most of this refuse is paper and paperboard; the plastics content is approximately 2 percent.

Characteristics of This Segment

As mentioned in the previous section, the supermarket receives his stock from two major sources. Most comes directly from his own warehouse, and the delivery is made with the company's delivery truck. But, some products come directly from a packager, who uses his own truck. In general, supermarkets would like to reduce the volume of their stock coming via this ‘‘direct delivery’’ route. Record keeping with these outside drivers has been difficult, and money often has been lost because of poor records.

The retailer also is an important decision maker in the plastics cycle. Today, when retailers are being swamped with an average of 100 new products monthly, he is continuously making go/no-go judgments concerning any new product on the market. In making his decision, the retailer's overriding consideration is to obtain adequate profits. With retail operation costs rising faster than retail prices, the retailer continues to fight the narrow-profit-margin squeeze. Other factors involved in the acceptance or rejection of a new item are: (1) need, (2) the sales potential it may enjoy in relation to other items within the same category, (3) the number of duplicate items stocked in that category, (4) the suggested retail selling price, (5) the extent of the manufacturer's promotional and advertising program that will help move it off the shelf.

In considering the package itself, the retailer considers: consumer appeal, ease of handling, attractiveness, and its ease of display. For example, the packaging of items in loose envelopes, tapering closures, odd-shaped cartons, or tippable glass jars is discouraged. Other obvious

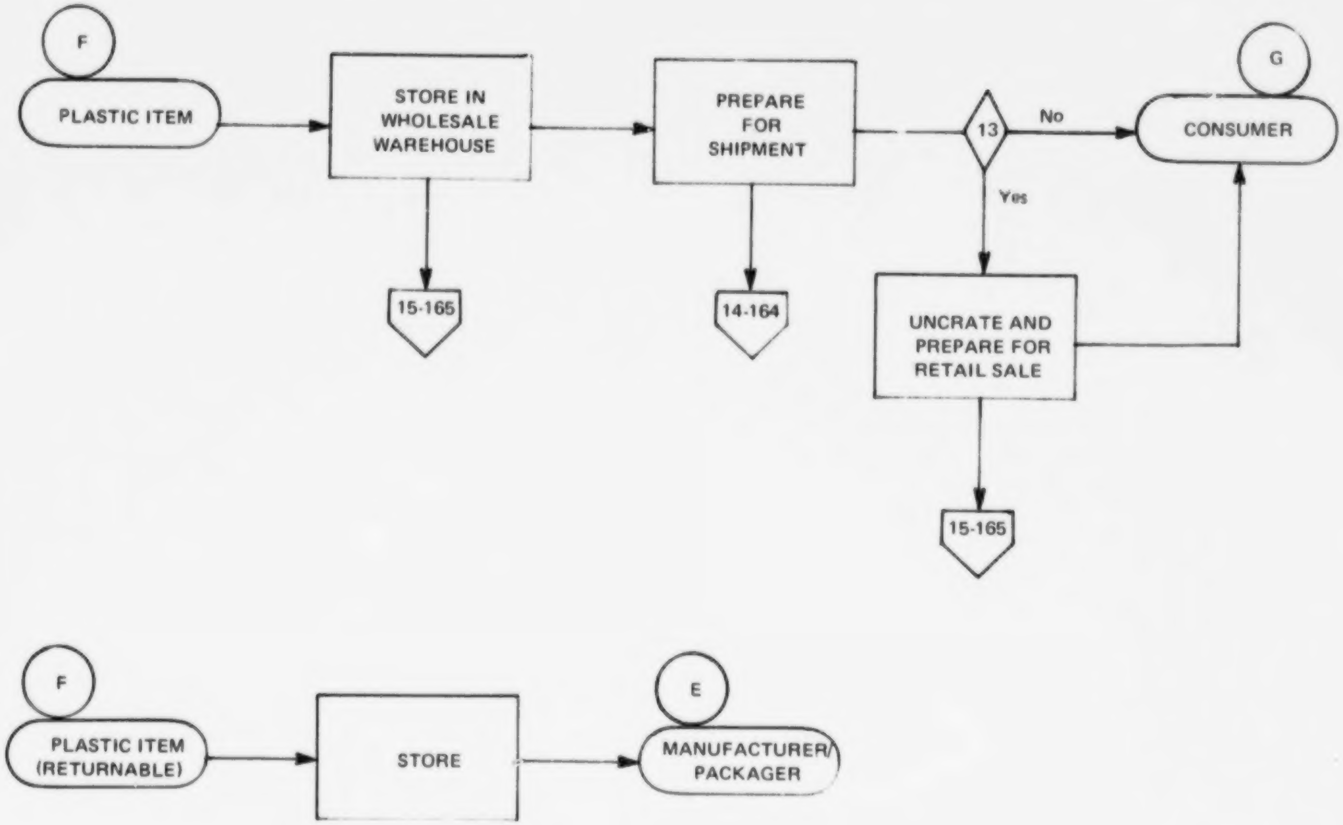

F
PLASTIC ITEM
STORE IN WHOLESALE WAREHOUSE
15-165
PREPARE FOR SHIPMENT
14-164
13
No
Yes
G
CONSUMER
UNCRATE AND PREPARE FOR RETAIL SALE
15-165
F
PLASTIC ITEM (RETURNABLE)
STORE
E
MANUFACTURER/ PACKAGER

Figure 34. The wholesaler/retailer. The wholesaler/retailer also generates NP that is contaminated with non-plastic wastes.

package faults are shelf hogging, ease of cap switching, difficulty of in-case place markings, proneness to pilferage, and breakability rate. With the tightening squeeze on shelf space, supermarkets today are beginning to ask packagers the same question the government often asks ''Do you need all those sizes for one product?''

Returnable Bottles

The only example today of a returnable plastic bottle is the high-density polyethylene milk bottle that is used in the system developed by the USI Division of National Distillers. This is the so-called ''polytrip'' system. The containers used in this system are heavier than one-way polyethylene milk bottles. These milk bottles are used primarily in home delivery and in jug-milk stores. Few supermarkets handle them. The bottles carry a deposit, and the returns are very good. USI claims that trippage runs between 200 and 300 fillings per bottle. This figure is based on the purchasing habits of the dairy in replacing containers to meet their daily filling requirements. In California, where state law prohibits the use of a deposit, the returnable plastic bottles were not returned and, therefore, they are not being used.

Approximately 87 dairies use these bottles at present, in contrast to the approximately 1100 dairies using one-way plastic milk bottles. The bottles that are returned are tested with a special hydrocarbon detector which can process 95 bottles per minute. If the hydrocarbon level exceeds 10 ppm, the control device punches a hole in the bottle making it unusable. This detector unit has the approval of the U.S. Public Health Department and is mandatory in most states for Grade-A standards in fluid-milk operations. In the filling operation they have found that only 0.1 percent of the returned bottles are rejected.

This issue of returnable versus one-way bottles is a political one today. With the gradual demise of the returnable bottle, the supermarket manager says ''good riddance,'' and the environmentalist protests. In fact, recently constructed supermarket stores do not have space alloted for bottle return. For the supermarket, this bottle-return operation is a costly one in terms of bookkeeping, space, and labor; furthermore, all of these costs have been rising. According to one of the Vice President's of a large supermarket concern, the labor costs alone for this type of collection amount to approximately 1 cent per bottle.

THE CONSUMER

The consumer really does not consume most products, particularly plastic ones; he merely uses them for a period of time that corresponds to the service life. Thus, a plastic product in the hands of the consumer only becomes NP when it is of little value to him. The estimated average service lives of various plastic products are listed in Table 35. For example, packaging, novelties, and disposables have a service life of less than one year, whereas products such as instruments and hardware can serve for 11 to 20 years, and items of construction usually last for at least 25 years.

Disposal of Scrap Plastic

We have compiled a list of the packaging wastes (most of which are generated by the consumer) according to resin type and type of packaging that includes our estimates of the NP generated from this source from 1970 to 1980 (Table 36). Because most packaging materials reach the disposal area within one year, the estimates for packaging wastes for 1970 were made using production statistics for that year. Plastic packaging is classified as rigid or flexible; an example of flexible packaging is plastic film, and example of rigid are plastic bottles, cups, etc. Packaging wastes, on a weight basis, are almost equally divided into these two classes (Table 37). However, considering that rigid packaging includes empty bottles, on a volume basis these wastes are the major packaging wastes. Table 30 also shows that almost 90 percent of all plastic packaging is monoplastic and, therefore, potentially recyclable. Looking ahead to 1980 (Figure 35), we do not see any major changes in the composition of packaging wastes by form. Although the production of composite and multiplastic film will increase during this decade, rigid monoplastic containers will still be the major plastic packaging waste on a volume basis.

Not only is packaging predominantly monoplastic, but that made from polyolefins predominates (Table 38). The polyethylenes alone account for close to 80 percent of all plastics in packaging, and we believe that the polyethylenes will continue to dominate this market during the coming decade. PVC in packaging, on the other hand, is only 6 percent of the total, and we do not believe that it will increase its share of the market during the next ten-year period. Table 38 only includes the estimates for the "big five" thermoplastics. If the plastic beverage container becomes a reality in the 1970's, plastic packaging wastes could increase to 12 billion pounds per year by 1980, instead of the estimated 10 billion pounds.

The consumer is primarily an NP generator, who disposes of a plastic item as its service life expires (Figure 36). In addition to the packaging wastes, the consumer disposed of over 1.6 billion pounds of other types of NP in 1970 (Table 39). Estimates in Table 37 are shown for 1970, '75, and '80, according to the type of product. The volume of NP generated by each product category was computed by considering the average service life of the product and the annual volume consumed the year the product was made. For example, housewares, which have an average service life of approximately 5

TABLE 35

SERVICE LIFE OF VARIOUS PLASTIC PRODUCTS*

Product	Estimated life (years)
A. 0-5 years	
Packaging	<1
Novelties	<1
Photographic Film	<1
Disposables (Dinnerware, hospital goods	<1
Construction Film	2
Footware	2
Apparel	4
Household Goods	5
Toys	5
Jewelry	5
B. 5-10 years	
Sporting Goods (Recreation, boats)	7
Automotive	10
Phonograph Records	10
Luggage	10
Appliances	10
Furniture	10
Cameras	10
C. 10-30 years	
Wire and Cable	15
Business Machines	15
Miscellaneous Electrical Equipment	15
Hardware	15
Instruments	15
Magnetic Tape	15
Construction	25

* Source: A. D. Little, Inc.

TABLE 36

PACKAGING WASTES†

Code no.	Resin type	Type of packaging: Physical form	Type of packaging: Composition	NP generation (million pounds) 1970	1975	1980
10.81101	HDPE	Rigid	Monoplastic	815	1440	2230
10.82101	LDPE	Rigid	Monoplastic	105	135	170
10.83101	PP	Rigid	Monoplastic	50	70	100
10.84101	PS	Rigid	Monoplastic	430	745	1285
10.85101	PVC	Rigid	Monoplastic	140	235	350
				1540	2625	4135
10.82201	LDPE	Rigid	Composite	240	260	285
10.82401	LDPE	Flexible	Monoplastic	1655	2845	4700
10.83401	PP	Flexible	Monoplastic	75	100	130
10.84401	PS	Flexible	Monoplastic	15	20	25
10.85401	PVC	Flexible	Monoplastic	100	155	235
				1845	3120	5090
10.82501	LDPE	Flexible	Composite	190	230	280
10.82601	LDPE	Flexible	Multiplastic	85	150	280
10.83601	PP	Flexible	Multiplastic	25	60	100
				110	210	380
ALL PACKAGING				3925	6445	10170

* Source: A. D. Little, Inc.

† Does not include Construction and Agricultural Film, but does include cups and refuse bags.

TABLE 37

TYPES OF PLASTIC PACKAGING (1970)*

Type of packaging+		Consumption	
Physical form	Composition	(billion pounds)	Wt %
Film	Monoplastic	1.84	47.0
Film	Multiplastic‡	.30	7.6
Rigid	Monoplastic	1.54	39.3
Rigid	Composite	0.24	6.1
TOTAL		3.92	100.0

* Source: A. D. Little, Inc.

+ Including cups, refuse bags, and industrial packaging, except for Construction and Agricultural Film.

‡ Including Composites

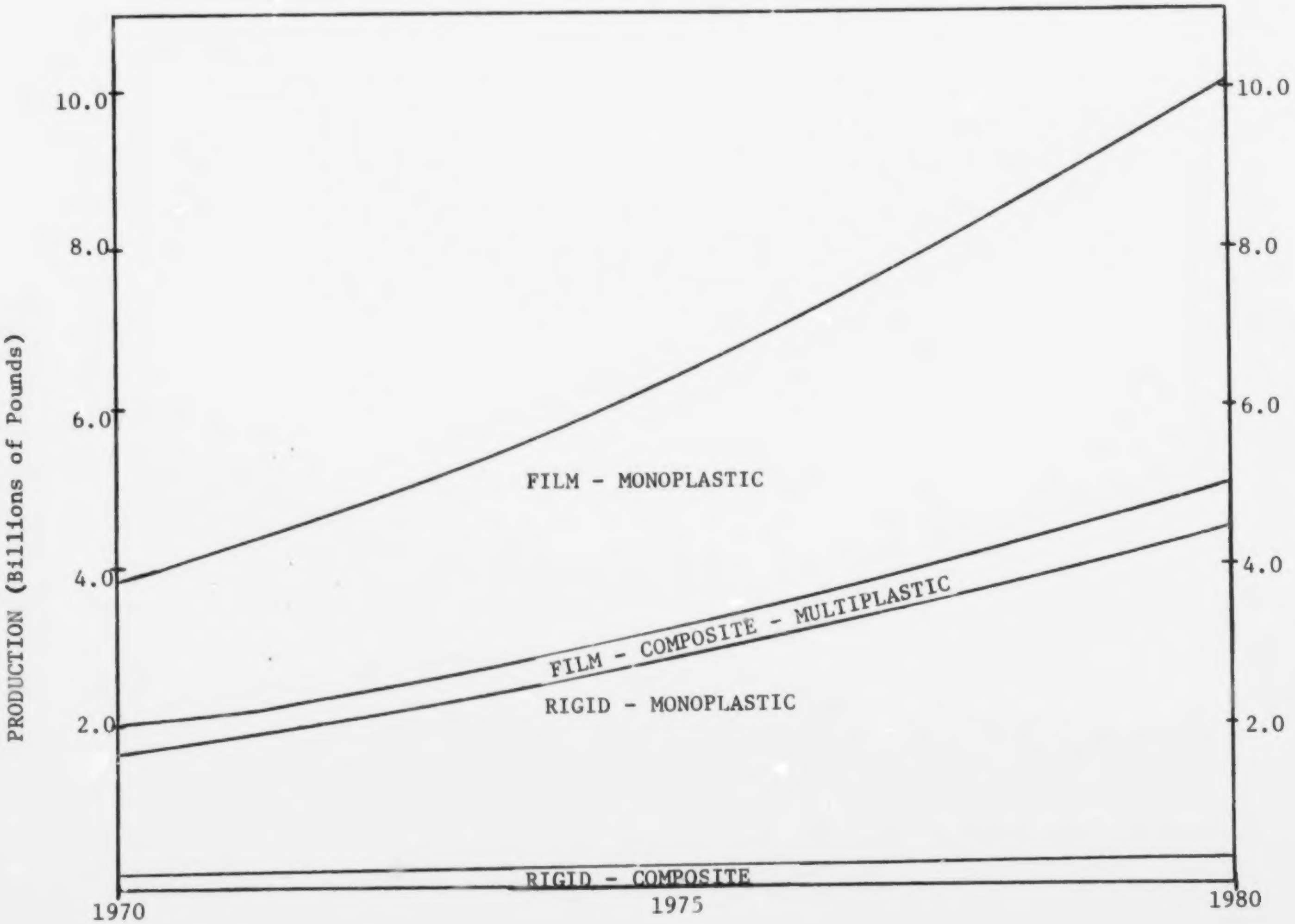


Figure 35. Packaging Wastes. The composition of packaging wastes will remain essentially unchanged during this decade.

TABLE 38[*]

ESTIMATED VOLUME OF PLASTICS IN PACKAGING[†] ACCORDING TO TYPE OF PLASTIC

Type plastic	1970		1975		1980	
	MM lb	Wt %	MM lb	Wt %	MM lb	Wt %
HDPE	815	20.8	1440	22.4	2230	21.9
LDPE	2275	58.0	3620	56.0	5715	56.3
Polypropylene	150	3.8	230	3.6	330	3.2
Styrene Polymers[‡]	445	11.3	765	11.9	1310	12.9
PVC	240	6.1	390	6.1	585	5.7
TOTAL	3925	100.0	6445	100.0	10170	100.0

[*] Source: A. D. Little, Inc.

[†] Includes cups and refuse bags.

[‡] Includes ABS

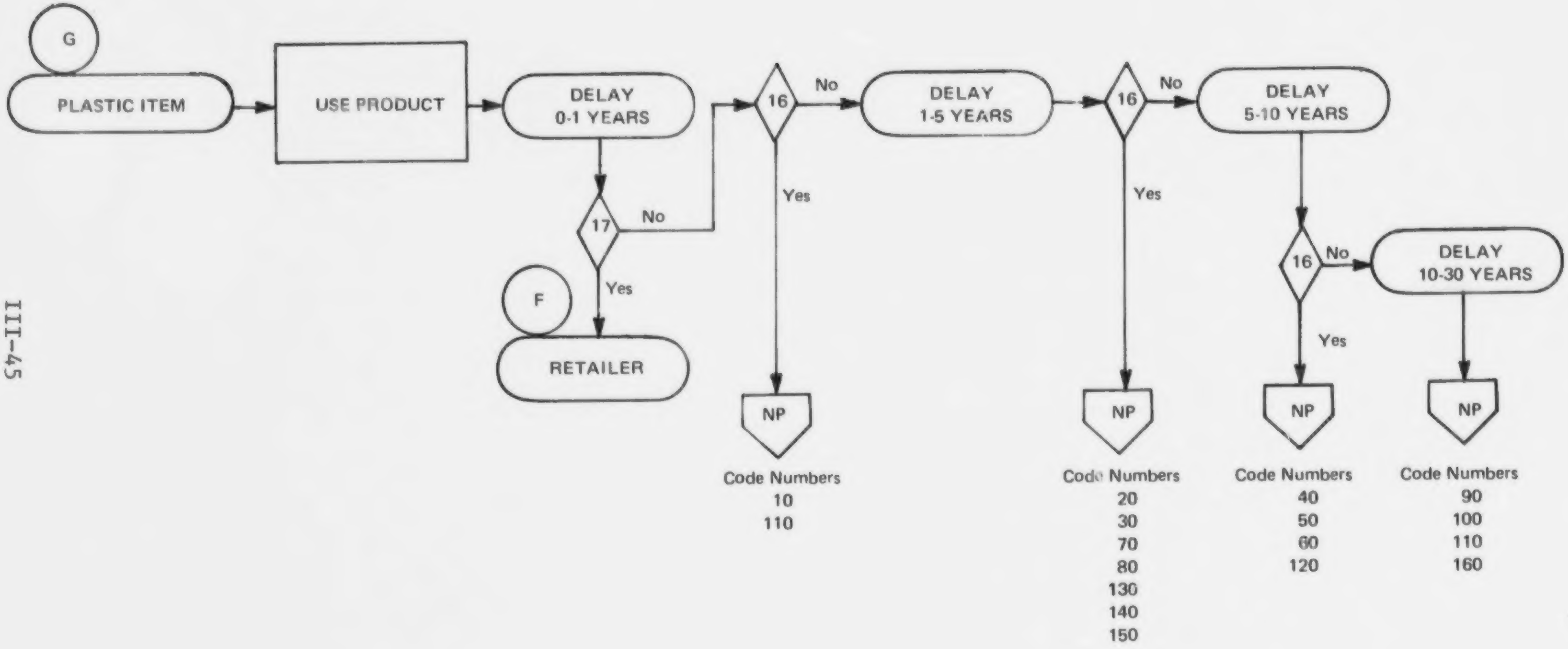

G
PLASTIC ITEM
USE PRODUCT
DELAY 0-1 YEARS
17
No
Yes
F
RETAILER
16
No
Yes
NP
Code Numbers
10
110
DELAY 1-5 YEARS
16
No
Yes
NP
Code Numbers
20
30
70
80
130
140
150
DELAY 5-10 YEARS
16
No
Yes
NP
Code Numbers
40
50
60
120
DELAY 10-30 YEARS
NP
Code Numbers
90
100
110
160

Figure 36. The consumer. The consumer disposes of nuisance plastics as the service life of the plastic item expires.

TABLE 39

ESTIMATED VOLUME OF NUISANCE PLASTIC FROM CONSUMER ITEMS OTHER THAN PACKAGING*

Code no.	Type of product	1970	1975	1980
20.84005	Housewares	115	205	320
20.85005		70	100	150
20.86005		240	580	800
20.87005		425	885	1270
30.84005	Toys	135	265	465
30.85005		55	60	80
30.86005		120	230	400
30.87005		310	555	945
40.84010	Transportation		35	85
40.85010			190	225
40.86010			25	160
40.87005		90	250	470
50.84010	Appliances		190	365
50.85010			10	20
50.86010			30	55
50.87010		100	230	440
60.84010	Furniture		30	90
60.85010			140	255
60.86010				10
60.87010		60	170	355
70.85002	Footwear	90	140	190
80.82002	Construction & Agriculture (Film)	130	195	285
90.87025	Construction	50	100	150
100.81015	Wire & Cable		2	230
100.82015				30
100.85015			95	220
100.87015		40	97	480
110.87001	Novelties, Disposables	100	200	400
120.87007	Sporting Goods	30	65	130
130.87005	Luggage	35	60	110
140.85005	Records	95	140	205
150.85004	Apparel	45	80	140
160.87015	Business Machines	10	25	50

* Source: A. D. Little, Inc.

years, generated 425 million pounds of NP in 1970. This was estimated by using the consumption statistics for the year 1965. Correspondingly, using the statistics for 1970, the value for NP generated in 1975 was estimated at 885 million pounds.

Analysis of the NP generated by the consumer, for example in 1970, shows that over 90 weight percent of the NP is derived from plastic products that have a service life of 0 to 5 years (Table 32). Moreover, the dominance of these spent plastic items of short service life in the disposal area will continue during this decade. However, during this same period, NP derived from spent plastic products having a longer service life will grow from 7 to 13 percent, primarily because more plastics are being used today in relatively long-life products such as automobiles, appliances, and wire and cable.

Nuisance plastics generated by the consumer are diluted by many types of materials, as they enter the solid-waste stream. Furthermore, the composition of refuse from this segment changes depending upon the season of the year and various socio-economic factors. Data on the composition of municipal refuse in the United States are limited, and most of the information has been developed by the Environmental Protection Agency.

According to the data from 9 different investigations that specifically identified plastics in urban wastes, solid wastes contain an average of 1.4 weight percent plastics.[9] This was calculated on a yard-waste and miscellaneous-free basis, which avoids the large variability in the composition of the refuse from the consumer by removing the dilution effect caused by variations in the amount of yard waste (grass clippings, tree prunings, etc) and miscellaneous materials (rocks, demolition wastes, etc) thrown in the refuse. This value for the percent plastics includes 13.8 percent moisture to take into account the moisture exchange process in refuse. High-moisture refuse components such as food wastes lose moisture, and the initially dryer components such as paper, rags, and plastics gain moisture. After such a process, the weight distribution among the various refuse categories is different. Therefore, on a dry basis urban solid wastes contain an average of 1.2 percent plastic.

It is of interest to compare the value found for the percent plastics in urban solid wastes with that computed from our estimates of NP generated. As Table 40 shows, 5.5 billion pounds of NP were generated by the consumer in 1970. However, this estimate is based on NP generated by the ‘‘big five’’ thermoplastics (coatings excluded), which accounts for 67 percent of all plastics consumed in 1970. Considering all plastics (i.e., thermoplastics, thermosets, and coatings), we estimate that the NP generated by the consumer is approximately 8.3 billion pounds, or a little over 4 million tons per year. According to a national survey,[10] about 250 million tons of solid waste per year are generated in the U.S. from household, commercial and municipal sources. Therefore, the urban solid-waste stream contains

TABLE 40

ESTIMATED VOLUME OF NP GENERATED BY CONSUMER (1970)*

Service life of spent plastic	1970		1980	
	MM lb	Wt %	MM lb	Wt %
0-1	4,025	72.7	10,570	67.0
1-5	1,130	20.5	3,145	19.9
5-10	280	5.0	1,395	8.8
10-30	100	1.8	680	4.3
TOTAL	5,535	100.0	15,790	100.0

* Source: A. D. Little, Inc.

approximately 1.6 weight percent plastics, which is in good agreement with the value found.

Based on our estimates in Table 40, 15.8 billion pounds, or 7.9 million tons, of nuisance plastics will be generated by the consumer in 1980 using the ''big five'' thermoplastics; we estimate that 11.8 million tons of NP will be generated by the consumer from all plastics that year. Assuming that waste generation will follow the 4 percent rise in per-capita purchases, and considering the increase in national population by 1980, we estimate that over 450 million tons of urban solid waste may be generated at that time. Thus, the percent plastics in urban solid wastes will rise to approximately 2.6 percent by 1980.

Paper, metal, and glass are the major components in the national refuse from household, commercial, and municipal sources (Table 41). Computations in this table were made on a yard-waste free and miscellaneous-free basis.[9] Yard wastes, which vary according to the local climate, are sometimes as high as 26 percent of the total urban refuse waste and, on the average, demolition wastes are about 4 percent. These wastes further dilute the NP in the waste stream from the home.

Staudinger,[11] in his study of plastic wastes in England, has shown how the plastics content varies in urban refuse. For example, he found that the plastics content is highest in winter refuse, irrespective of the neighborhood. The seasonal peak in January may be due to residual aftereffects of Christmas. He also indicated that people living in ''flats'' generate more NP than those living in the middle-class or ''artisan'' neighborhoods. Presumably, those living in flats lack the opportunities for on-site disposal of packaging wastes in boilers, fireplaces, or garden incinerators.

Staudinger also analyzed the plastics in Birmingham (England) refuse in 1969 according to source and type of plastic (Table 42). Recently, the Bureau of Mines in Rolla, Missouri also carried out a study.[12] About 800 lbs of plastic discards from households were collected and analyzed to determine the concentration of each plastic. Their findings are also listed in Table 42, where they are compared with our estimates. As the table shows, the agreement between the values computed and the values found is very good; the polyolefin NP predominates in all cases. The high PVC content of the Birmingham refuse (9.6 percent) may be an error because other plastic containers could have been mistaken for PVC. In the Rolla study about 1700 bottles were collected. These collected bottles were sorted and characterized according to the market that they serve (Table 43).

The Airlines. As mentioned earlier, the consumer in this segment includes institutions as well as householders. Some institutions generate solid wastes that are richer in nuisance plastics than those from the householder. For example, the airlines use many disposable plastic items such as drinking glasses, swizzle sticks, creamer cups, and polyethylene film and bags.

TABLE 41

ESTIMATED ANNUAL AVERAGE NATIONAL REFUSE COMPOSITION*†

Component	Mean weight (%)
Glass	9.9
Metal	10.2
Paper	51.6
Plastics	1.4
Leather, rubber	1.9
Textiles	2.7
Wood	3.0
Food wastes	19.3
Total	100.0

* Source: W.R. Niessen and S.H. Chansky. The nature of refuse. *In* proceedings; 1970 National Incinerator Conference, May 17-20, 1970. New York, American Society of Mechanical Engineers. p. 1-29.

† On a yard-waste-free and miscellaneous-free basis.

TABLE 42

NP FROM CONSUMER--COMPARISON OF ESTIMATES WITH VALUES FOUND

	Sources		
	A. D. Little	Staudinger*	Bureau of Mines†
% Packaging wastes	71	72	-
% Non-Packaging wastes	29	28	-
In packaging wastes			
% Flexible	45	54.6	-
% Rigid	55	45.4	-
% Polyolefin content	82.6	71.7	75.7
% PVC content	6.1	9.6	4.8
% Polystyrene content	11.3	19.3	19.5

* Reference 11
† Reference 12

TABLE 43

BOTTLES IN PLASTIC SAMPLE COLLECTED IN COMMUNITY*

Detergent	57%
Cosmetic	11%
Food	14%
Medicine	13%
Other	5%

* Source: Reference 12

On a typical flight, they normally use several polyethylene bags for ice alone, and a large number of molded polystyrene cups. Over 100 million cups were used by the airlines in 1970, which is equivalent to approximately 3.6 million pounds of general-purpose polystyrene. If a mechanism for collection were developed, this NP could become an excellent resource.

After they have been used, most of these cups are discarded in one of the trash bins in the aircraft. These bins are usually emptied by the airline personnel after the flight. Of course, these trash bins usually contain not only the plastic drinking glasses, but other types of solid wastes accumulated in a flight. Nevertheless, the solid waste stream from the airliner itself has a higher concentration of plastic wastes than that from the normal consumer.

Characteristics of This Segment

The household consumer in the U.S. is a member of a very affluent society. Today, there are 203 million Americans living on 3 percent of the earth's surface who earn approximately $756 billion a year, spend more than $500 billion and save about $33 billion.

Today, over two-thirds of our people live in metropolitan areas, and many more live in cities and towns outside these areas. In the 1960's, more than three-fourths of our nation's growth occurred in metropolitan areas with the suburbs absorbing most of it, and suburbanites now outnumber those living in central cities.[13]

Let's look ahead now to 1985 when the U.S. population will be between 240 and 250 million.[14] If past trends continue, nearly half of our national population will be living in the suburban parts of our metropolitan areas in 1985. This will give rise to an expansion of the metropolitan areas and is expected, therefore, to result in a continued decrease in population density. Furthermore, there will be a dramatic rise in the number of younger adults; the next 15 years is seen as the era of the young married. Experts believe that American families will have far greater incomes in 1985 than they have today. The average family income is expected to rise from $8,600 today to $15,000 in 1985, measured in dollars of constant purchasing power.[14] Most of the added purchasing power will occur in the 25-44 age group.

What will this affluence mean in terms of solid waste generation, and in particular, the generation of plastic wastes? Considering packaging, which is the major source of consumer NP, we have found that the consumption of packaging materials is directly related to the national per capita income.[15] Statistically, the results of this comparison were highly significant, and the correlation was excellent.

Packaging is primarily a service function, and it is well known that service functions tend to be ''income elastic;'' that is, as incomes grow, the portion spent on the services increase at a greater rate than income. Packaging services usually grow at a higher rate than incomes for the following reason: (1) because more packaging is consumed per item purchased; (2) because a greater variety of goods enter into consumer budgets; (3) because a greater number of goods are packaged as national income grows.

Society today has developed a new life style that will further increase the amount of packaging wastes. The household consumer will be using new packaging for kitchen-ready, oven-ready, table-ready, quick, and carry-out services. Less attention is given to formal meals today and, therefore, the demand for snack and supplement-type foods has been increasing rapidly. We expect that more and more people will be ''eating meals on the fly,'' and by 1975 many predict that 50 percent of the food will be consumed away from home. Thus, more packages will be designed for travel, while other packages will move where the people are. For example, there will be an increase in vending, portion-packs, fast service, etc. Needless to say, these single portion-packs usually consume more packaging materials per product than bulk containers, and plastics are set to take full advantage of these new opportunities to satisfy packaging needs.

Consumers prefer plastics to other materials for packaging frozen food, dairy products, drugs, cosmetics, and toiletries. They like plastic bottles in particular because they are lightweight, easy to handle, and non-breakable[16]; in other words, these containers are convenient. ''Convenience'' is a key work in today's society, and apparently the consumer is willing to pay. Perhaps he is unaware that he does pay, but when he buys a can of beer, 43 percent of the sales price is for the package alone; in a one-way bottle, the same beer includes a 36 percent charge for the package. Still another example--the cost of baby food in a glass jar includes a 36 percent charge for the package.[17]

Although the ultimate objective of all plastic manufacturers is to satisfy the needs of the consumer, the consumer usually has difficulty in communicating those needs. The very fact that independent consumer testing organizations have evolved confirms a major communications gap between the consumer and the manufacturer. While advertising serves the manufacturer, what about communications in the other direction? How does the consumer tell the manufacturer about his product and his package? Clearly, the consumer communicates by what he does or does not purchase at the retail store, but he can only make a selection from those products that are made available to him. Because packaging is only part of the total product promotional system, the effectiveness of most packages cannot be isolated based solely on sales statistics.

Only in recent years have the consumers taken steps to make their voices heard. The establishment of the Consumer Advisory Council of the Executive Branch of the U.S. Government is a clear indication of the significance of consumerism in our political environment today. Thus the consumer, frustrated with his inability to communicate with the manufacturer, has established a new and indirect communication channel through the government. As a result, politicians, who recognize the opportunity to serve their constituents, have been quick to jump in response to the wave of consumerism currently sweeping our society. Unfortunately, this indirect channel has its own difficulties, for most politicians do not really know what's troubling the consumer. Again, the dilemma of the returnable vs. non-returnable bottles is a case in point. While pollution-minded consumer groups press for a swing back to the use of returnable bottles, the majority of U.S. consumers have accepted the convenience of the one-way bottles and are willing to pay the premium required to eliminate the annoyance of bringing the bottles back to the supermarket.

THE DISPOSER

The disposer can be a public agency, a private contractor, an individual householder, or an industrial firm. According to a national survey,[10] 12 percent of household and commercial wastes are self-collected and transported to disposal sites, 32 percent are handled by private contractors, and 56 percent by municipal collection agencies. Considering only industrial wastes, approximately 55 percent are disposed of by the industrial concern on his own site, and the remaining 45 percent are handled by private contractors who dispose of them either in private or municipal sites.

Plastics in the Disposal Area

Industrial Sources. In previous sections of Part III, we listed the various sources and volumes of NP generated by the manufacturing operations involved in converting plastic resins to an end plastic product. A total of approximately 1 billion pounds of NP were generated by these operations in 1970 (Table 44). Fabrication and converting operations are responsible for most of the industrial NP, and together these account for almost 60 percent of the total. PVC predominates in the industrial wastes (Table 45); it accounted for approximately 34 percent of the total in 1970. As mentioned previously, large quantities of PVC wastes are generated, because PVC is more difficult to process than the other major thermoplastics, and it is used in numerous formulations. The second major industrial waste is low-density polyethylene; it accounted for about 30 weight percent. We believe that these wastes from LDPE and PVC will continue to predominate in the industrial plastic wastes generated during this decade (Table 45). Also

TABLE 44

SOURCES OF INDUSTRIAL NP
(1970)*

Operation	Million lb.[+]	Wt. %
Polymerization	200	20.0
Compounding/Reprocessing	110	11.0
Fabrication	320	32.0
Converting	260	26.0
Other[‡]	110	11.0
TOTAL	1000	100%

*Source: Arthur D. Little, Inc.

[+] Numbers have been rounded to the nearest 10 million lb.

[‡] Wastes generated in distributing products from manufacturer/packager to consumer.

TABLE 45

INDUSTRIAL WASTES (NP) ACCORDING TO PLASTIC TYPE*

Type of plastic	1970 Million lb.	1970 wt.%	1975 Million lb.	1975 wt.%	1980 Million lb.	1980 wt.%
HDPE	68	6.8	142	7.8	260	8.5
LDPE	316	31.7	582	31.9	977	32.0
Polypropylene	84	8.4	200	10.9	402	13.2
Styrene polymers	193	19.4	340	18.6	547	17.9
PVC	336	33.7	563	30.8	867	28.4
ALL TYPES	997	100.0	1827	100.0	3053	100.0

*Source: Arthur D. Little, Inc.

note from this table that NP from industrial sources will triple during the next ten-year period and will amount to approximately 3 billion pounds by 1980.

All Sources. According to government statistics, over 260 million tons of refuse (probably closer to 400 million tons) are generated from urban and industrial sources today; of this total, only 190 million tons are collected by private and municipal collection agencies. We have estimated that 6.5 billion pounds of nuisance plastics (based on the "big five" thermoplastics) were generated in 1970 from all sources. If all plastic wastes (thermoplastics and thermosets) are included, then approximately 9.7 billion pounds or 4.8 million tons were generated in 1970. Thus, plastic wastes from all sectors were 1.4 to 1.2 weight percent of urban and industrial solid wastes. By 1980, the volume of all nuisance plastics should rise to about 14 million tons, and urban and industrial solid wastes to about 650 million tons. At that time, therefore, the calculated value for the concentration of nuisance plastics in the urban and industrial solid wastes will be about 2.2 weight percent.

An examination of the sources of all nuisance plastics derived from the "big five" thermoplastics in the disposal area and the volumes generated by these sources show that the major NP source is that from packaging (Table 46 and Figure 37); it corresponds to about 60 percent of all NP in the disposal area. More surprisingly, however, is manufacturing wastes. Thus, these two types of NP account for 75 percent of all plastics in the disposal area. Notice that housewares, which is the third category, only account for about 6 percent of the total NP. Moreover, these other types of consumer NP would be difficult to recycle, because they are usually part of a composite.

The data in Table 46 indicate that the percentage of plastic packaging wastes in the disposal area will drop slightly during the next ten years. This decrease will occur because more and more plastic items with long service lives will enter the solid waste stream. For example, in 1980 wastes from such durable goods as wire, cable, and furniture will account for a much greater portion of the NP (2.5 and 1.9 percent, respectively). Even if plastic beverage bottles generate 2 billion pounds of NP by 1980, plastic packaging wastes as a percentage of all NP in the disposal area will still not increase during the next ten years.

Of all nuisance plastics in the disposal area, polyolefin wastes will continue to dominate throughout the coming decade (Table 47). We estimate that these wastes will account for approximately 65 weight percent of the total NP. Note from the table that PVC wastes from all sources represent about 17 percent of the total, while PVC wastes from packaging are only 6 percent. We believe that the concentration of PVC wastes from all sources will either remain constant or perhaps decrease slightly over the next ten-year period. Accordingly, the percentage of PVC wastes from industrial

TABLE 46

NUISANCE PLASTICS IN THE DISPOSAL AREA[*]

	1970		1975		1980	
Type of product	Million lb.	wt. %	Million lb.	wt. %	Million lb.	wt. %
Packaging	3925	60.1	6445	56.2	10,170	54.0
Footwear	90	1.4	140	1.2	190	1.0
Records	95	1.4	140	1.2	205	1.1
C and A Film[†]	130	2.0	195	1.7	285	1.5
Industrial Wastes	1000	15.3	1830	15.9	3,050	16.2
Toys	310	4.7	555	4.8	945	5.0
Transportation	90	1.4	250	2.2	470	2.5
Appliances	100	1.5	230	2.0	440	2.3
Furniture	60	0.9	170	1.5	355	1.9
Wire and Cable	40	0.6	95	0.8	480	2.5
Novelties, Disposables	100	1.5	200	1.7	400	2.1
Others [§]	120	1.8	230	2.0	430	2.3
Housewares	425	6.5	885	7.7	1,270	6.7
Construction	50	0.8	100	0.9	150	0.8
TOTAL	6535		11,465		18,840	

[*] Source: A. D. Little

[†] Construction and Agriculture

[§] Includes business machines, instruments, luggage, sporting goods, apparel.

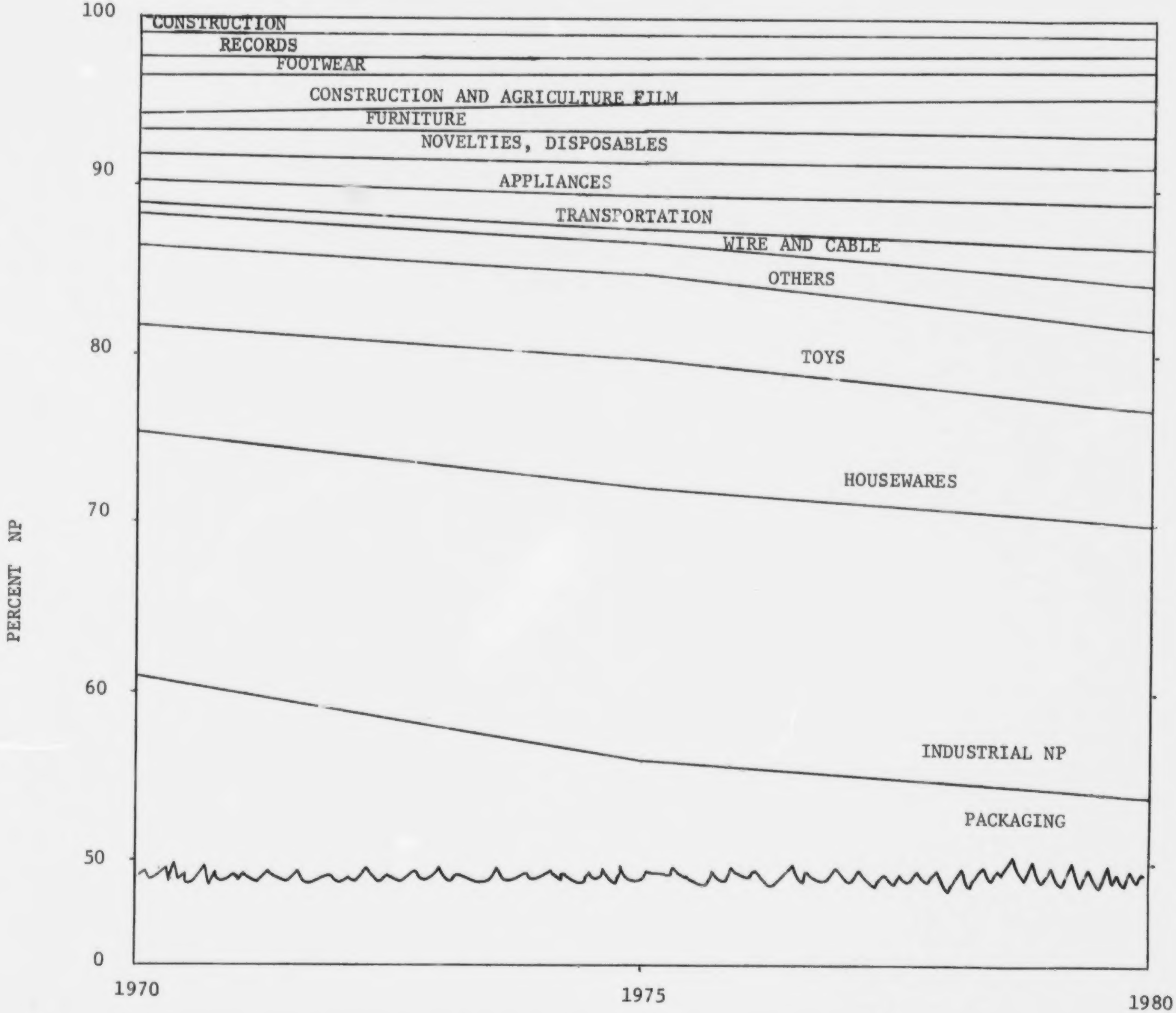


Figure 37 . Plastics in the disposal area. (Source: ADL)

TABLE 47

PLASTICS IN THE DISPOSAL AREA FROM ALL SOURCES*
According to Type of Plastic†

Type of plastic	1970		1975		1980	
	mm lb	wt.%	mm lb	wt.%	mm lb	wt.%
Polyolefin	4,218	66.9	7,276	66.1	11,884	66.0
Styrene polymers	993	15.7	1,830	16.6	3,182	17.7
PVC	1,096	17.4	1,908	17.3	2,937	16.3
All types	6,307	100.0	11,014	100.0	18,003	100.0

*Does not include business machines, instruments, luggage, sporting goods, novelties, disposables, and construction.

†Source: Arthur D. Little, Inc.

and consumer sources is, on the average, only 0.24 percent of all urban and industrial solid wastes.

Intermediate Disposal

Whether the NP is generated by a consumer or a manufacturing firm, it usually goes into an intermediate disposal area or storage facility (Figure 38). In the case of the householder, this is normally a garbage can, and in the case of the manufacturer it may be a large trash bin that is emptied mechanically.

Plastic wastes in storage are troublesome primarily because they have low specific gravities and, more significantly, they have low bulk density and occupy large volumes of space. This is particularly true of empty plastic bottles. The average density of completely compressed plastics is approximately 70 pounds per cu ft, whereas the density of uncrushed plastic wastes can be 1.6 pounds per cu ft.[11] Jensen, in a study by the Bureau of Mines,[12] indicated that plastic wastes from packaging have a density of 3 pounds per cu ft. Compare this with the average density of solid waste in the United States in the uncompressed form which varies from 7 to 18 pounds per cu ft.[18] Thus, uncompressed plastic waste is 1/4 to 1/7 as dense as most uncompressed solid waste. Accordingly, assuming a 1.4 weight percent value for plastics in solid wastes in the intermediate disposal area, where there normally is little compression, then on a volume basis, this would amount to 5.6 to 9.8 percent. To keep this in perspective, note that other non-plastic packaging wastes such as paper cartons, boxes, tin cans, glass bottles, and aerosol containers also have low bulk density. Recently, appliance manufacturers have developed ''trash mashers'' that compact solid wastes to approximately 1/4 of their original volume in 60 seconds. These units are specifically designed to handle these bulky items.

The costs of intermediate disposal to the consumer or the industrial manufacturer are not included in the $4.5 billion cost often cited for handling the 3.5 billion tons of solid wastes* in the U.S. Furthermore, these costs are extremely variable and would be difficult to estimate. For example, what is the cost to the householder to separate his refuse? How should this be estimated? The facts are that in many cases the household consumer does separate his refuse when he stores its. Commonly he separates wet from dry refuse, and garbage-disposal units in many homes automatically remove much of this wet refuse. In some communities, for example, solid waste is separated into combustibles and non-combustibles and some householders

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*1.5 billion tons animal wastes
1.1 billion tons mineral wastes
550 million tons agricultural and crop residues
360 million tons urban and industrial wastes

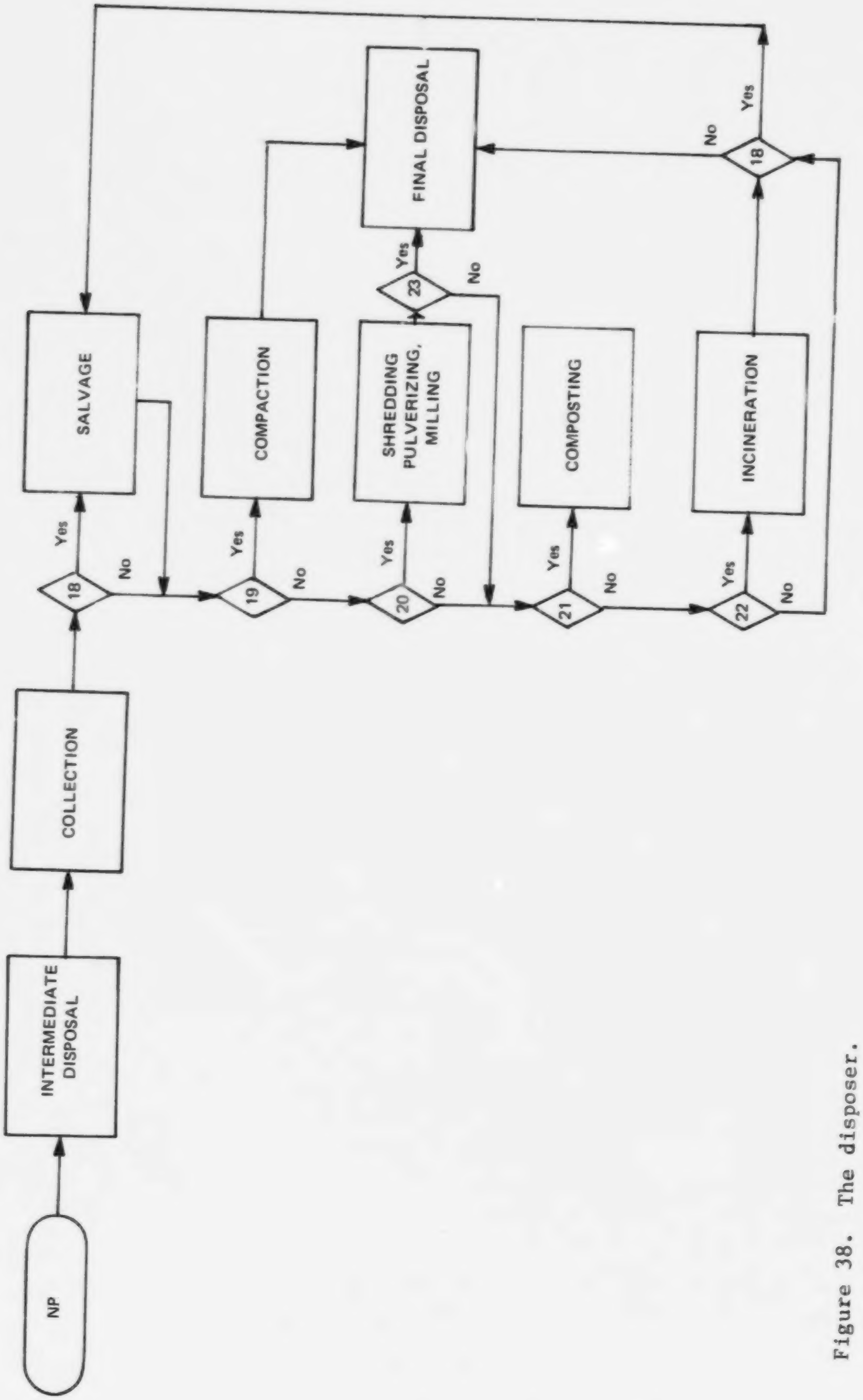
NP
INTERMEDIATE DISPOSAL
COLLECTION
18
Yes
No
SALVAGE
19
Yes
No
COMPACTION
20
Yes
No
SHREDDING PULVERIZING, MILLING
23
Yes
No
FINAL DISPOSAL
21
Yes
No
COMPOSTING
22
Yes
No
INCINERATION
18
No
Yes

Figure 38. The disposer.

separate old newspapers for collection. Accordingly to the former Bureau of Solid Waste Management,[7] at least 30 percent of the householders in the U.S. practice some form of separation in the home.

Collection

In collection, the low bulk density and the high area-to-weight ratio of plastic wastes are again troublesome. For example, thin plastic films are easily scattered in the collection process during the transfer of refuse from the garbage can and during discharge of the refuse at the final disposal site. The use of polyethylene refuse bags helps avoid this problem, and today more and more communities use these to reduce the labor costs of collection. If a compactor truck is used for collection, some compaction can occur, although this is seldom greater than a 50 percent reduction in volume. Based on a recent government survey of 47 communities, about 70 percent of the community-owned collection vehicles are compactor trucks, 23 percent open dump trucks, and 8 percent enclosed non-compactor trucks.

The collection process typically involves considerable manual handling, and it is generally a labor-intensive process. Therefore, collection costs often constitute between 50 and 75 percent of the total disposal cost and vary from $5 to $20 per ton.[19] Again, the low density of plastic wastes directly affects the cost of collection. Not only are trucks filled up sooner; but if a large number of garbage cans are required to hold the low bulk density waste, the refuse collector makes more than one trip between the home and the refuse truck and the labor costs increase.

Industrial firms have similar collection problems. Often their fees for refuse collection services, in contrast to those of the householder, are assessed on the basis of the volume of the container and the frequency of collection. Using volume as a basis for the service charges further reaffirms the significance of non-crushable plastic containers, which increase refuse bulk at a net cost to the waste generator. As a result, some manufacturers today practice on-site containerization of refuse, and some refuse containers are equipped with hydraulic compactors that not only assist in filling the container but provide a level of compaction comparable to that of a packer truck.

Treatment Processes

When refuse has been collected and accumulated in sufficient quantity to justify some processing prior to ultimate disposal or further handling, a number of operations can be carried out to recover usable values or to improve the economics of subsequent disposal. These include salvage, compaction, shredding, pulverizing or milling, composting, and incineration. Generally these treatment processes represent some level of technology, and they increase capital costs. Also, they represent areas now receiving the greatest attention on the part of investers and municipal authorities.

Salvage. Following the flow diagram in Figure 38, note that salvage operations can occur before final disposal or after incineration. Today salvage is primarily practiced in the recovery of paper and ferrous metal. Overall, the percent refuse that is segregated for salvage is extremely small. Most tin can salvage operations are practiced on the residue of the incinerator rather than the refuse as it comes from the packer truck. New methods for salvage are currently under investigation, and some of these are discussed in Part IV.

Baling. With the decreasing availability of land-fill sites near the areas of high refuse generation, longer haul distances to alternate disposal sites are being required; therefore, further densification of the refuse to reduce transfer costs has become more attractive. Most compaction today is carried out with comparatively conventional baling equipment. In some cases, baling has been preceded by shredding to reduce the refuse to a more easily deformable state.

Baling equipment can increase the density of refuse to as much as 65 pounds per cu ft, which is approximately 30 percent greater than that achieved in good sanitary land-fill operations. Compaction costs range from 50 cents to as high as $3.00 per ton. The differences in cost reflect partly economies of scale and partly the degree of treatment. In general, plastic films deform readily in compactors without shredding and, other than their low inherent specific gravity, they do not affect the ultimate bale density. Plastic bottles and toys undoubtedly offer greater resistance to compaction, but there is little information on problems they cause in baling operations.

Pulverizing, Shredding, and Milling. Any treatment that converts refuse into a more particulate state, whether it is done by pulverizing, shredding, or milling, is advantageous in any subsequent process. Pulverized refuse, for example, is most useful where it is intended for the restoration of land sites and landscape improvements.

Pulverization costs range from $1 to $3 per ton depending on the particle size of the final product and the economies of scale. The effect of plastics in the pulverization operation depends not only on their properties such as hardness, impact resistance, flexibility, resilience and rebound characteristics, but also on the physical form in which they are introduced. For example, rotating-drum-type pulverizers have little disintegrating action on plastics in general, although brittle or thin wall articles such as records, rigid foam, packaging trays, etc., are cracked and broken by the churning and tumbling action.

Most plastics are ungrindable in conventional hammer mills, because many plastic articles such as those made from plasticized PVC or low density polyethylene bottles are resilient and have a high degree of elasticity. On the other hand, rigid polystyrene moldings or those made from phenolic resins and other hard plastics are readily shattered and broken up in a mill. Recently, certain types of hammer mills have become available that can easily accommodate plastic wastes.

Composting. Another treatment that also is a way of utilizing solid waste is composting. Composting is essentially the biodegradation of refuse or a portion of it to produce a humus-like material. Although plastics are not compostible, because they are not susceptible to rapid biodegradation, they have not been reported to cause significant problems if the refuse is shredded. Fine plastic particles merely behave as any other inert material like grit, small stones, or slate; therefore, they would not be expected to have any detrimental effects on the root development and growth processes of plants.

Composting has not been an effective way of disposing of municipal solid waste in this country. Despite its very early use as a soil conditioner and fertilizer in Europe, composting has made little progress in the U.S. This lack of progress has been due to the low cost and wide use of chemical fertilizers and the high operating and distribution cost of compost. Thus, the number of successful composting operations in the United States has been limited and municipalities have been reluctant to enter into this type of commercial operation.

Incineration. One of the basic methods for destroying wastes is by burning or incineration. Volume reduction for most urban wastes after incineration ranges from 70 to 80 percent, and weight reduction is between 60 and 80 percent.

Behavior of Plastics. Incineration is basically a high temperature oxidation process. Thus, plastics, which contain primarily carbon and hydrogen, are oxidized to carbon dioxide and water vapor provided the conditions of time, temperature, and turbulence are right. When thermoplastics are heated, they become progressively softer and gradually melt; when the temperature is increased further, the viscosity of the melt decreases until it becomes a fluid. This generally occurs between 150 C and 250 C. In some cases, as with polystyrene, the polymer depolymerizes and often degrades or decomposes at or near its melting point. On the other hand, when thermosetting resins are heated, they generally do not deform but simply degrade. Because thermal decomposition starts from the outside, all materials with high ratios of surface to volume melt and decompose fairly rapidly. Conversely, the larger the article the more slowly it burns in the incineration process.

Most plastics have a high calorific value, often equal to that of high grade fuel oil. For example, polyethylene has a fuel value of 18,000 Btu per pound; in contrast, PVC, which has chlorine in addition to carbon and hydrogen, has a value of only 9,500 Btu per pound.

The polyolefins burn relatively easily and give off no noxious gases; however, they tend to drip, and the drops often continue to burn. When burned in the open, polystyrene, which has a self-ignition temperature of 900 F, burns with a yellow flame throughout and develops dense smoke. PVC, on the other hand, burns with difficulty; burning has to be sustained by an outside heat source. PVC softens and chars, and if no plasticizer is present, it does not drip. On burning, PVC generates 58 pounds of hydrogen chloride per hundred pounds of polymer.

Extensiveness of Treatment. Incineration is most commonly used in metropolitan areas where high population density often prevents the use of land fill, and where high total population results in the generation of large quantities of refuse. At present, about 20 to 25 percent of the commercial and domestic waste collected in the urban centers is treated by incineration; this amounts to about 10 percent of the total waste collected in the U.S. (urban and rural areas included). By the year 2000 we anticipate that the fraction of refuse incinerated in urban areas will increase to almost 30 percent.

Within the operating lifetime of many active municipal incinerator plants, municipal incineration technology has advanced from the early handstoked hearth units to the contemporary mechanically-stoked water-wall boilers. The pace of design innovation has been greatly accelerated in recent years by Federal assistance through demonstration grants. Nevertheless, looking ahead to the next ten years, we believe that most incineration will still be carried out in units now in existence and in units greatly resembling those now in use. According to a recent survey by the Environmental Protection Agency, there are only about 3000 municipal-type incinerators (capacities in the hundreds of tons per day) and of these only about 25 percent are rated as operable within current air and water pollution restrictions.

The Process. In the incinerator system, the handling of refuse begins with the delivery of materials to the site. In some cases compaction has occurred in the packer vehicle; such refuse has a density of 15 to 30 pounds per cu ft. The refuse is then stored temporarily in a pit where further densification can occur. Again, plastics are troublesome because they have low bulk density. However, because the pit and the associated transfer crane that is used to transfer the refuse to the incinerator constitute only 5 to 10 percent of the total incinerator plant costs, plastics only have a small effect on this aspect of plant economics.

From the pit the refuse is usually fed into the incinerator system and, in all but a very few old furnaces, the refuse then sits on a metallic grate where it is burned. These grates are fabricated from materials such as cast iron and various high-alloy stainless steels. In some portion of the burning process active burning begins at grate level, and the refuse is rapidly elevated to high temperatures. Under such conditions plastics (thermoplastics) have been known to fuse and close off the openings of the grate. If the plastic melts, it also can flow through the grates and cause undergrate fires with consequent grate damage.

In most plants, the furnace enclosure is constructed of refractory brick, but in the more modern plants in Europe and in a few places in the U.S. continuous water walls are used. Water-wall construction consists of steel tubes laid side by side and welded together to form panels which are in turn formed into walls of the furnace. In recent years, there has been considerable concern with the corrosive effects of the hydrogen chloride from PVC on the refractory wall materials but, more importantly, on the metal water walls. The alumina in the refractory wall furnaces can react with the hydrogen chloride to give aluminum chloride, which can volatilize under the temperature conditions of the furnace.

Following the initial combustion processes, which occur in the primary chamber, there is usually a secondary chamber to provide for the more complete burnout of combustible materials. Once again, the older plants use refractory construction in the secondary chamber, but some of the new plants use water-filled metal tubes. In some European plants, where metal tubes are used, corrosion has been noted, and hydrogen chloride is suspect.

The next major unit of the incinerator is a gas-cooling device such as a water-spray evaporative cooling system. Again, aqueous hydrogen chloride can cause a corrosion problem. This problem is compounded if air pollution devices are used, because these often can include substantial areas of unprotected metal. Many problems associated with the scrubber water arise from its acidity, which is as low as pH 2 after a single pass. This acidity can rapidly degrade unprotected metallic surfaces, pipes, etc, and has caused catastrophic failure of scrubbers and fans. Furthermore, the treatment of waste water from such scrubbers represents a substantial cost, and it can be a potential source for water pollution. Only in the past few years have true wet scrubbing systems, as differentiated from crude spray chambers or wet baffles, been applied to municipal incinerators; fewer than 10 percent of the municipal incinerators have them today.

Corrosion. At present, old incinerating systems that were not designed with the recognition of these corrosion problems suffer significant down-time maintenance charges. Unfortunately, however, such costs are difficult to document and are not only associated with the hydrogen chloride content of the flue gases but also reflect the action of sulfur and organic acids as well as improper operation.

Not withstanding what has been said above, there are large modern incineration plants in operation today which, after several years, have shown insignificant or no signs of corrosion. Often the absence of corrosion has been attributed to the partial removal of HCl from the combustion gases by its reaction with alkaline materials such as carbonates and silicates in the refuse. d'Hondt[20] described the results of tests in which the normal refuse was supplemented with 3.25 percent PVC. They noted that only a small portion of the theoretical amount of HCl expected could be detected in the gases. They also mentioned that if the incinerator operated at sufficiently high temperatures (above dew-point conditions), PVC presented virtually no risk of corrosion. On the other hand, K. Matsumoto[21] noted that when industrial PVC waste was added to the urban refuse in an incinerator inordinately high amounts of HCl were present in the flue gases (2,000 ppm). Also, severe corrosion occurred in the high temperature region of the incinerator.

A clear statement concerning the corrosive effect of HCl from PVC is difficult to make, because corrosion can be caused by poor operating conditions, uneven addition of plastics to the burning refuse, other acid producing wastes, and other artifacts. Recently Prof. Elmer R. Kaiser, in a study sponsored by the Society of the Plastics Industry, added double and triple amounts of plastics to the normal solid waste loads and burned them in a relatively recently constructed municipal incinerator. He added PVC, polystyrene, polyethylene, and polyurethane, and found that large amounts of plastics (up to 6 percent) in the solid waste mix did not have a corroding effect on the incinerator during the operating period. The short operating period of these experiments makes these findings questionable. The incinerator was one that employed a conventional continuous feed system with oscillating grates and processed an average of 200 tons of mixed refuse a day. Prof. Kaiser also reported that the incineration of plastics in these large amounts caused no significant increase in smoke levels and did not increased pollution in the atmosphere. During the tests, the plastics did not drip through the incinerator grates. In fact, the higher burning temperatures of the plastics improved the incinerator performance, particularly when the normal refuse was wet.

Burning Polystyrene. As the discussion above indicates, PVC is the most troublesome plastic in an incinerator. Polystyrene also can be difficult, although it does not produce corrosive or noxious gases. Polystyrene burns easily in an incinerator if the rate of heat release, which is approximately 18,000 Btu per pound as opposed to 4,000 Btu per pound for normal refuse, is controlled.[22] The very high rate of heat release must be retarded to insure complete combustion. Common methods to control this heat release are to cut the air supply and/or maintain a small ratio of polystyrene to normal refuse. The thick black smoke which can be generated in burning polystyrene is eliminated by using an efficient after burner.

Costs. As a treatment process, incineration is relatively expensive; incineration costs range from as low as $2 per ton to as high as $8 per ton. The average is approximately $5.30 per ton.[19] Incinerators require a large capital investment; construction costs vary from $1500 to more than $6000 a ton at a rated 24-hour burning capacity. Upkeep costs are also relatively high, and more skilled employees are required. Labor costs are a significant part of the operating costs of an incineration plant (Table 48). Plastic wastes can affect these economics by requiring more resistant materials of construction or heightened maintenance due to the more rapid corrosion of refractory and metal parts.

Industrial and Commercial Practices. Increasing costs of collection and disposal compounded by increasing rates of refuse generation have led many industries, shopping centers, hotels, etc, to dispose of their own solid wastes by incineration. In many cases, the savings from reduced requirements for refuse storage and less frequent refuse collections together with the elimination of the aesthetic and unhealthful accumulation of waste are sufficient to justify the installation and operation of a private incinerator. While there are several types of incinerators that are effective for industrial solid waste, those which do not have grates that plug easily are more widely used where plastic wastes are involved. In this case, rotary kiln types have been used successfully both in the U.S. and in Europe. They can incinerate solid waste containing relatively high proportions of plastics (up to 30 percent of the charged weight). The rotary kiln types are preferred because they afford excellent blending and mixing of the refuse during the combustion process. Any pool of molten plastics that forms under the refuse bed is continuously exposed to the combustion air by the rotation of the drum.

As might be expected, the incineration of industrial waste is more likely to produce pollutants than the incineration of domestic refuse; therefore, safeguards are required. Specially designed incinerators are available for burning scrap PVC, and in some instances, these allow the recovery of HCl for reuse.

Residue. Residues may be found in four locations in incinerator systems--on the grate, beneath the grate, in the secondary combustion chambers, and in the air pollution control device. Grate residue consists primarily of non-combustibles such as metal cans, wire, foils, etc, and slow burning refuse such as books, catalogs, and high moisture materials. Plastic solidified from the melt sometimes adheres on or adjacent to the grates; this must be broken with a hammer to be removed. Residue falling through the grates consists primarily of fine ash, aluminum, broken glass, etc, but it also may contain chunks of plastics that have solidified. Residues from the incinerator usually go directly to a final disposal site such as a land fill. In some instances, as mentioned above, metal cans are salvaged from these residues.

TABLE 48

ESTIMATED COST OF INCINERATION USING BATCH INCINERATION SYSTEMS*
(1969 dollars)

Reference location: Boston, Massachusetts, mid-1969
Plant capacity: 400 TPD (two, 200-TPD furnaces)
Load factor: 250 days per year; 3 shifts/day
Annual consumption: 100,000 tons refuse/year
Capital investment: $2,300,000

	Units	Dollars/Unit	Units/Ton Refuse Consumed	Dollars/Ton Refuse Consumed
Variable Costs				
Electricity	kwh	$0.015	22.3	0.33
Water	M gal	0.30	0.90	0.27
				$0.60
Semi-Variable Costs				
Labor				
1 crane operator per shift @ $5.00/hour				0.31
2 furnace operators (stoking and dumping) per shift @ $3.00/hour				0.38
1 charging floor man per shift @ $3.00/hour				0.19
2 residue removal men per shift @ $3.00/hour				0.38
1 supervisor @ $14,000/year				0.14
1 weigh scale operator @ $5,500/year				0.06
				$1.46
Overhead @ 40% of labor and supervision				0.58
Maintenance and repair @ 2.5% of capital investment annually				0.58
				$2.62
Fixed Costs				
Amortization @ 4.7% of capital investment annually				1.08
Interest on loan @ 3.0% of capital investment annually				0.69
				$1.77
Total Costs				$4.98

*Source: Arthur D. Little, Inc.

Final Disposal

Most of the treatment processes described above produce a modified form of the original NP; however, after incineration, plastics leave little residue. If the NP is not treated, it usually undergoes little more than mild compaction during the simple operation of the compactor truck. Eventually, however, a point is reached where further volume reduction would be too costly, or where local economies dictate direct disposal.

Land Fill. At this time, the solid waste is normally delivered to a land fill or, in a few instances, transferred to barges for subsequent ocean dumping. More than 90 percent of the household, commercial, and industrial solid wastes are handled by some type of land fill. Costs include capital investment of about $2000 per ton and $1 to $2 per ton as operating costs.

The practice of land fill can range from an open burning dump to a truly sanitary land fill operation. This latter operation is basically one of spreading refuse on the ground; in some instances, the refuse is densified by burning or by mechanical means using a compaction vehicle, and afterward covering the refuse with a layer of clean earth. In the case of the open burning dump, many plastics are undoubtedly subjected to some measure of volume and mass degradation with an accompanying emission of air pollutants. Where compaction vehicles are used to densify the refuse, many plastic items are ruptured and reduced in volume.

Behavior of Plastics. Plastic materials generally do not decay or rot even after prolonged soil burial and, therefore, they represent some of the most persistent components in the fill. For example, plastic bottles are not easily squashed, and only those in the lower strata of the refuse become distorted, flattened, or compressed by the overlying weight. Those with less weight or overburden are likely to remain intact and can, therefore, contribute to the springiness of the top layer. Accordingly, whatever process is used to compress refuse on-site or off-site, the results will be a reduction, if not a complete elimination, of the deleterious effects that plastics may have in land fill. If plastic bottles are properly squashed, they lose much of their springiness, although some shapes tend to unsquash more than others.

The public has often attacked plastics because they are not biodegradable. However, as recently pointed out by some officials of the county sanitation district of Los Angeles, there are no meaningful differences between plastics and decomposible materials when used in a sanitary land fill. In fact, they state that because plastics can be considered the equivalent of an inert material such as broken concrete, plastics are better suited than decomposible materials for land fill disposal, because they provide immediate stability. Here again, plastics are most suitable if they are in a pulverized form.

Biodegradation is dependent on time and the geometry of the article in the disposal area. Rausing[23] recently reported that he examined plastics that were buried in a dump in Sweden for five years. While heavy plastic parts were found, thin plastic films had already disappeared. He also reported that after five years the molecular weight of the polyethylene in refuse was 1/4 of the original, whereas the molecular weight of PVC in refuse was 2/3 of the original.

Litter

We have discussed the disposal of plastics through normal channels, but as anyone who travels our highways and walks in our cities realizes, solid wastes are often disposed of as litter. In a recent survey by the Highway Research Board of the National Research Council,[24] litter was analyzed along a one mile stretch of an ordinary two lane highway. This litter consisted of 770 paper cups, 730 empty cigarette packs, 590 beer cans, 130 soft drink bottles, 120 beer bottles, 110 whiskey bottles and 90 beer cartons. Obviously, packaging wastes are the wastes that predominate in roadside litter. Using a random sample of approximately 10 highway segments each 2/10 of a mile in length in 29 different states, the Highway Research Board found that 59 percent of all items were paper, 16 percent were cans, 6 percent were plastics, 6 percent were glass bottles and jars, and 13 percent were miscellaneous. The total litter volume correlated with the average daily traffic.

Plastics, although only 6 percent of litter according to this study, are significant because they are durable and visible. Furthermore, the costs of collecting litter of any type are very high. In New York City, for example, they have estimated that it would cost as high as 30 cents per unit to pick up bottles.[25]

PART IV

SCRAP AND NUISANCE PLASTICS: ISOLATION, APPLICATIONS, AND MARKETS

APPLICATIONS FOR SCRAP AND NUISANCE PLASTICS

A key factor in promoting the recycling of plastics is the availability of markets for the scrap material once it has been collected and segregated; but the existence of markets obviously depends on the development of applications for this scrap. Whenever possible, reuse should be considered, for a fabricated container, for example, is usually worth about three times the cost of the raw material. If reuse is not possible, then recycling should be promoted. The order of preference, in decreasing order, is as follows: primary, secondary, and tertiary.

Reuse

The best example today of reuse is the returnable polyethylene milk container that is used in the ''polytrip'' system developed by U.S. Industrial Chemicals Co. (USI), a division of The National Distillers and Chemical Corp. As discussed in Part III, these returnable bottles are heavier than the plastic one-way containers. A half-gallon returnable plastic bottle weighs approximately 140 g; in contrast, the one-way gallon plastic container weighs 90 g. Before filling, the returnable bottles are annealed to prevent any change in volume during the high-temperature washing operation that is required in the ''polytrip'' system. According to USI, relatively few dairies who started using these returnable bottles discontinued their use, which indicates little dissatisfaction either by the dairy or the consumer.

With the use of returnable plastic containers in food applications, obviously there has been considerable concern about contamination. As mentioned in Part III, USI uses a hydrocarbon detector to eliminate contaminated bottles from the filling line. USI has stated that to date there has been no court litigation resulting from claims of contaminated bottles from installations using their detector. Testing done by Washington State University and by the U.S. Public Health Service indicated that poisons that are non-hydrocarbon in nature do not penetrate polyethylene unless they, in turn, are suspended in a hydrocarbon carrier. Of course, these hydrocarbons would trigger the USI detector.

Furthermore, USI reported that polyethylene bottles that have undergone sixty use cycles had no rancid odor; however, tests following extraction of these containers with chloroform indicated that the concentration of butter fat absorbed in the polyethylene was approximately 900 ppm. Apparently, the butter fat does not go rancid within the plastic mass because microorganisms or enzymes cannot penetrate the plastic together with the butter fat.

As mentioned above, the USI detector only tests for hydrocarbons; it does not detect solid impurities. Another instrument is available and in use for detecting solid material in milk bottles whether they are made from glass or plastics. It is called ''dairy scan'' and is produced by the Wheinelleur Company of St. Louis, Missouri. If solid impurities are present, they are detected, and the bottle is moved aside.

Another approach to promote the reuse of plastic containers has been developed by a new company that was formed in 1970. Their process de-inks mislabeled plastic containers from packagers and labelers. This de-inking process can be used to remove decorations printed by silk-screen and flexographic techniques, and the company charges approximately 25 percent of the cost of the new bottle for this service. Most of this company's customers are custom decorators.

Note that this de-inking process is being used only for plastic containers that have not yet reached the consumer. Technically, there should be no difficulty in using this process for salvaging spent plastic containers from the consumer segment; but, markets for these used containers are presently non-existent. No doubt, these used containers could be used for non-food applications, if the markets could be developed. Furthermore, there also is the question whether these containers that have been designed primarily for one-way usage will be able to withstand the handling involved in de-inking and refilling. Nevertheless, it may be possible to develop a market for these spent containers to package products such as industrial chemicals. If necessary, heavier containers could be especially fabricated for reuse, similar to the returnable plastic milk bottles now available.

Primary Recycling

If reuse is not possible, then primary recycling is preferred. As a general rule, scrap plastic must be used in an end application that can tolerate lower performance specifications than the product yielding the scrap. However, there are a few instances where the scrap can be recycled back into the same product. As pointed out in Part I, much of the recycling that occurs in the fabricator's facilities is primary recycling. For example, much of the ''pinch-off'' in a blow-molding operation is recycled in bottle manufacture. A major requirement for primary recycling is a very clean stream of scrap, thus if the fabricator is careful, he can recycle much of his own scrap.

One intriguing possibility for the primary recycling of consumer scrap is the possibility that the individual plastic milk cartons used in schools or other institutions, if collected, could be granulated, washed, and reprocessed into new polyethylene milk containers. Under these controlled environmental conditions, severe contamination of the plastic containers is very unlikely. Thus, a clean stream of scrap could be provided. We know of no examples of this type of recycling today, but this approach is worth exploring. If reuseable polyethylene milk containers meet the approval of the Public Health authorities, we see no reason why these recycled containers cannot be used. Reprocessing scrap at the elevated temperatures attained during processing should produce a sterilized product.

A new recovery process on the horizon which can promote primary recycling is one that extracts plasticized PVC from its fiber substrate. This is the scrap that is obtained in large volumes from the upholstery manufacturers (both automotive and furniture), as described in Part III. The extraction process uses an entirely closed reclamation unit and, reportedly, there is no effluent to the atmosphere, ground, or water. The solvent which is used to extract the PVC compound is recycled for reuse, and the fiber substrates, which are usually cotton, are recovered and sold as scrap for use in making paper. Fiber Process, Inc. (FPI), Piqua, Ohio, has applied for patents on this system.

This process is promising because the PVC can be recovered in crumb form containing the original plasticizer and stabilizer. No additional stabilizer is required during the recovery. Furthermore, the reclaimed PVC processes on the calender more easily than the virgin product. The automobile industry, which is following this technology closely, has found that the reclaimed PVC meets their specifications. FPI believes that they can sell the recovered PVC at a price perhaps 20 percent below the price of virgin PVC compound, and they are also considering the possibility of providing their recovery services for a fee. Thus, they would reprocess the scrap from the fabricator and converter and return the reclaimed product to the fabricator for a service fee of approximately 10 cents per pound. This operation is being investigated in a pilot plant facility; however, FPI is considering constructing a plant capable of handling 50,000 pounds of trim per day in the very near future.

Secondary Recycling

Equipment. In the discussion of fabrication processes in Part I, we indicated that most fabricating machinery was designed with minimum tolerances for contaminants. Recently Werner and Pfleiderer Corporation, Warwick, New Jersey,[26] designed a low-pressure molding machine that can convert 100 percent polyethylene and PVC scrap from bottles and other products to new plastic products. Their process can accept film scrap directly, without grinding or intermediate processing. Even plasticized PVC up to 90-shore hardness and coated fabric scrap can be used as a raw material, because the machine has a specially designed plasticizer screw (patent pending) with axial grooves in the screw flights.

The low-pressure injection molding process (maximum clamp tonnage: 25 to 85 tons) has the additional advantage that it can use aluminum alloy and epoxy molds instead of those made from the more expensive hard steel. Not only does the use of aluminum molds save approximately 50 percent in tooling costs, but it also results in faster cooling and, therefore, faster overall cycle times. This equipment can make relatively large parts with shot-weights ranging from 2 to 5 pounds. The most beneficial results are achieved in the molding of heavy, thick-walled objects with large cross sections and with parts that do not require extremely close tolerances. This machine has been used in Europe to manufacture plastic products such as shoe soles, luggage handles, bicycle saddles and handlebars, hardware trimmings, toys, wheels for appliances, small containers, swimming fins and paddles, suitcase handles, containers, electrical items, and certain household utensils.

This company also has developed new compacting equipment that has the possibility of making products containing both scrap plastic and scrap fiber. In this equipment, ground fibers (polyester and nylon fiber wastes) together with plastics are forced through die openings at high pressures. The resulting product, which is in the form of pellets, is expected to be both moldable and extrudable. Presumably this process would be an answer to the reprocessing of polyester and nylon fiber wastes as well as plastic wastes.

Another process that has a good potential for reprocessing scrap plastic is coextrusion. As mentioned in Part I, this process can be used to extrude products where the core material contains scrap plastics--such products as hose, conduit, pipe, and sheet.

Recycling of Monoplastics. The largest potential for the use of scrap or nuisance plastics is in the secondary recycling, and a number of examples were cited in Part I. Tables 9 and 10 in Part I, for example, list the various applications for polyethylene and polyvinylchloride according to the performance requirements.

As Table 9 indicates, polyethylene used in the fabrication of bottles, film of high quality, and certain coatings must have tightly controlled specifications. In contrast, many plastic products made by molding or extrusion, whether they are housewares or extruded pipe, use resins having relatively wider specification ranges. Thus, scrap from plastic bottles, though usually difficult to recycle as bottles, can be used for pipe, pallets, and a variety of structural products. For example, much of the polyolefin scrap today is used in duct work in automobiles. Normally, these are dark colored products, and therefore colored scrap is easily used. Generally, automotive applications are good ones for scrap plastic.

However, in some instances, scrap from plastic bottles, such as those used to package milk and bleach, could be used to make other bottles to package products that do not require resin with very controlled specifications. For example, scrap from polyethylene milk bottles could be converted to bottles for packaging water, and scrap from polyethylene bleach containers could be recycled as detergent containers.

Scrap obtained from polyethylene-coated wire and cable is usually high quality but has very low melt flow. To use this scrap as raw material, additional compounding would be required to increase its flow. This product would then be similarly useful in extrusion and injection-molding processes.

Just as the polyethylene scrap generated from the products listed at the top of Table 9 can be used to make those products listed on the bottom of the list, so can PVC scrap be used according to the listing in Table 10. Thus, rigid PVC scrap from bottles or other sources can be recycled into pipe, conduit, moldings, and profiles. Flexible PVC scrap from film and sheet can be recycled into products such as certain wire and cable coatings, but the reclaimed compound would be most useful for moldings, profiles, and certain flooring. As pointed out in Part I, a major application for much of the flexible PVC scrap is the manufacture of garden hose where it is used as a core material. Flexible PVC scrap also can be used to make toys, weatherstripping, ''waterstop'' and profiles in general. To convert rigid PVC to flexible PVC is not out of the question. However, because the molecular weight of the rigid PVC is usually lower than that used for making flexible products, plasticization of rigid PVC scrap could present problems, and further study may be required.

In addition to some of the technical impediments towards recycling mentioned in Part I, other technical factors that must be considered include the need to use scrap with the appropriate additive for the end use. For example, if a cadmium-based pigment is present in the scrap, this scrap could not be readily recycled for a toy application or any other application where the plastic would be in contact with food because this pigment is poisonous. As mentioned previously, all plastics that are in contact with food require FDA-approved additives; therefore, the use of scrap plastic in food applications would be very difficult. Furthermore, scrap containing additives that are designed for one fabrication process occasionally interfere with the use of the scrap in another process. For example, a slip additive is usually added to polyethylene used for making film. Very often this additive interferes with the use of this scrap in molding applications. Certain inks also can hinder recycling, because they can promote degradation of the plastic material during the reheating process.

Pipe Market As An Outlet For Scrap Plastic. A major market for scrap polyethylene and PVC is plastic pipe. Plastic piping is growing faster than any other portion of the pipe market; pipe and fittings used 524 million pounds of resin in 1969 and will probably consume over a billion pounds by

1975. Today as much as 30 million pounds of secondary resin or compound are used in the manufacture of utility pipe for open drainage, drain tile, and a variety of non-pressure applications. The secondary pipe compound is usually a blend of off-grade resin and scrap plastic and is sold by the reprocessor/compounder to the fabricator for approximately 12 to 13 cents per pound. Low head irrigation pipe (17 psi), which is a 40-million pound market, is another area where secondary material could be used; but presently only virgin PVC is used.

Drain tile in particular is a good potential market for secondary resin. Tile comes in both corrugated and uncorrugated varieties, and ca. 30 million pounds of polyethylene went into this application in 1970. This represents a 30 percent penetration of a market where little plastic was used five years ago. By 1975 expectations are that corrugated plastic tubing may account for 60 to 70 percent of the total market.

Plastic drain tile competes with clay; both are approximately 10 cents per foot. The cost of this plastic tile includes about 5 cents per foot for manufacturing. But, plastic drain tile has a number of advantages. It is installed about 20 percent faster than conventional drainage tiles; misalignment problems are minimal, water intake is greater, and the plastic tubing is essentially impervious to alkalies and acids in the soil, which normally degrade concrete-based tile.

Unfortunately, many applications for secondary resin in pipe compounds are blocked today because the specifications of the Soil Conservation Service (SCS), Department of Agriculture, stipulate virgin materials. According to the existing regulations, the cost of installing drain tile or plastic tubing for soil conservation purposes can be depreciated as a capital investment in tax payments over a number of years, provided that the product meets federal and state specifications, for example, Soil Conservation Engineering Standard Practice for Drain Tile - Code 606 - Nov. 9, 1967. An FHA specification which similarly blocks the use of secondary materials is ‘‘Materials Release No. 619 June 4, 1969.’’ This specification refers back to the SCS Code 606 with respect to material standards. Code 606 stipulates that ‘‘compounds used in the manufacture of corrugated PE drainage tubing shall conform with requirements of Type 3, Grade 4, Class C polyethylene, as specified in ASTM 1248.’’ This ASTM specification, in turn, states that only ‘‘clean rework material generated from the manufacturer’s own production may be used by the same manufacturer, provided that the tubing produced is equal in quality to tubing extruded from virgin material.’’

In our meetings with several resin suppliers, they expressed the belief that polyethylene scrap obtained from spent polyethylene containers, if properly cleaned, could be used to make the type of pipe referred to in Code 606. For example, HDPE scrap from plastic milk containers, which has a density of 0.96, might be suitable, although it is probably too stiff for some pipe applications. However, scrap plastic obtained from bleach and detergent bottles has a density of 0.950 to 0.958; this would be satisfactory because it is more flexible. Flexibility is required in many pipe applications to make the plastic pipe coilable.

The Soil Conservation Service also requires virgin resin for all pressure pipe. As expected, this pipe requires resin with more controlled specifications than that used in non-pressure applications. However, the use of secondary resin should not be ruled out. This would have to be determined by actual tests. Some of these are very demanding. Thus, for some pressure-pipe applications the product has to pass 10,000 hours under tests for qualification.

To utilize scrap from rigid PVC bottles, compounding would be required to impart flexibility. Again, this material could be used in non-pressure, non-code, low-head irrigation-pipe applications. Other areas of application are telephone and power-cable duct work. In some of these applications modulus is important, and one way of obtaining this with scrap is to increase the wall thickness of the pipe.

At the present time, over 60 million pounds of styrene are used to make styrene-rubber pipe, which is used for sewerage, leeching, and as utility duct. Most of the styrene and rubber used in the manufacture of this pipe is secondary material. Unfortunately, because of the poor properties of these materials, they are being replaced by virgin PVC; although the use of rigid PVC scrap in this application is a possibility.

The largest market for plastic pipe, which has hardly been penetrated, is its use as sub-soil irrigation pipe. This pipe is perforated and 1/2 in. diameter and is utilized to irrigate arid land; some also is used for watering lawns. The pipe can be used advantageously because the water flowing through the pipe filters upward to the surface, thus offering good weed control and efficient use of scarce water. Secondary polyethylene could be used in this application, if the government supported it; therefore, large markets for secondary polyethylene could open up.

Polyethylene scrap obtained by granulating polyethylene bottles has actually been used to make plastic pipe. For example, Owens-Illinois ground up 5,000 polyethylene bottles and extruded them into 4 in. diameter drainage pipe.[27]

Jensen[12] at the Bureau of Mines tested the physical properties of this polyethylene scrap. Polyethylene bottles were chopped to pass through a 1/4 in. screen and the scrap was then washed in hot water to remove paper adhesives and any contaminating residues. When this granulated material was used alone in injection molding, the mold did not fill completely, although this could have been readily remedied by a simple modification of the mold. But, a mixture of virgin and scrap plastic did give a satisfactory product. Sample strips were cut from the moldings made with virgin, mixed and old scrap material, and some of the physical properties were measured (Table 49). These

TABLE 49

COMPARISON OF PROPERTIES OF INJECTION MOLDINGS FROM VIRGIN AND WASTE HIGH-DENSITY POLYETHYLENE *

Material	Hardness shore units	Tensile strength psi	Elongation percent	Specific gravity gms/ml
Virgin	39.6	4120	500	0.960
Mixed	38.8	4090	525	0.955
Scrap	38.4	3940	380	0.955

* Source: Reference 12.

data show that scrap polyethylene has substantially less elongation under tension but has tensile strength, hardness, and specific gravity properties relatively close to those of the virgin product.

Other Markets. The use of plastics in the construction of pallets is another area of high interest today. Though this represents a relatively small market for plastics at this time (about 10 million pounds), by 1980 the demand could increase to 300 million pounds of plastic materials. Potentially this market is a good one for secondary resins, particularly secondary polyethylene. One company who manufactures these pallets by a modified rotational molding process believes that they can easily use secondary polyethylene. This manufacturer claims that his pallets are designed to last as long as three years.

Structural foam is another important application for scrap plastic, particularly polystyrene. This foam, for example, could be used as a wood substitute and as a core material in various products. Thus, foamed scrap could perhaps be used as the sandwich material in a plywood laminate. A recent German patent[28] describes another application where the foam is shredded and applied to an adhesive-coated support. Several layers of support material and foam particles could be used to give a multilayered structure. The finished product can be used as insulation or as a packing material. Others[29] have mentioned the possibility of using rubbery polyurethane foam scrap as rug underlay. Here the shredded scrap would be mixed with adhesive, spread onto a belt, then compressed, bonded, cured, and rolled ready for packaging.

Composites. Another intriguing way of utilizing scrap plastic is to combine it with non-plastic materials in a composite. For example, Hemersan[30] indicated that he formed a composite by mixing chopped thermoplastic film scrap with scrap fibers and/or wood chips or particles and heating the formed mixture under pressure. In this way chip board was produced by pressing wood chips with particles of PVC film. A French patent[31] reports that hard insulating plastic foams for buildings, tanks, and pipes were prepared from hard foam scrap, together with cellulosic fibers and resinous binders. Another patent[32] that has recently been issued depicts a system where molten thermoplastics including scrap are sprayed together with fibers through a variety of nozzles onto an advancing conveyor to give a sheet material.

One of the major packagers is developing ways of utilizing the plastic-coated paper scrap from their manufacturing operations. They have used this composite material in a variety of ways; for example, as a coating for fiber-drum liners, as an up-graded cylinder board, and as a material for fabricating products such as soil pipe, bathtubs, etc. In general, this plastic-coated paper stock could find numerous applications as a wood substitute in the construction field.

The possibility of forming corrugated products from scrap plastic filled with low-cost reclaimed fiber (newsprint, old corrugated boxes, etc.) could represent a new approach to a rigid-when-wet paper product. Plastic corrugated products are being made today in both Japan and Germany, but these products are based on unfilled resin. Inclusion of a low cost, low-density filler could have a substantial effect on the raw material cost and, therefore, on the economics of fabricating these products.

The Japanese are using a different approach. The Japan Synthetic Paper Company has developed a system of reducing scrap plastic sheet into fine grains which are then remolded into sheets, boards, or containers, and other goods.

Another composite that is being actively considered today is a plastic-cement mixture. Apparently, plastics can improve the strength and chemical and water resistance of concrete and mortar. In a commercial operation today, the Japanese, for example, mix resin and cement together at a ratio of 1:10 to 1:20. Despite the technical success of this combination, Dow[33] claims that adding plastics to concrete generally isn't feasible at this time because the costs far outweigh the benefits.

However, adding plastic scrap is another matter. Hoffer Plastics Corporation[34] is currently co-operating with the Society of the Plastics Industry to develop uses for granulated plastic scrap in concrete. In their initial experiments, polyethylene scrap was used, although they indicated that other plastic materials could be similarly used advantageously; even a mixture of plastics could be used in this application. Hoffer replaced as much as 40 percent of the sand in concrete without adversely affecting the concrete's strength. Tests showed that the plastic-concrete samples were 10 to 15 percent lighter weight than the conventional mixes, and cement workers who poured a slab found the material stiff yet workable. It did not slump, which is advantageous in building free-form concrete structures. The concrete-plastic mixture also appears to have better crack resistance. Currently, this product is undergoing more extensive evaluation.

The Japanese have been conducting similar experiments with concrete-plastic composites, and the Japan Resources Technical Institute has developed a process for forming blocks from crushed plastic scrap and ordinary refuse using a compactor. The blocks are then coated with cement or asphalt and used for fill and embankment construction.

In Germany[35] they have constructed highway foundations using a mixture of scrap plastic and cement. Plastic improved the insulating properties of the foundation and, therefore, prevented extensive cracking during severe cold weather. Some test road strips made with this mixture of plastic and cement are still in perfect condition even after three years of use.

In a sense, scrap plastic in concrete is a filler, and in this application, mixtures of scrap plastics often can be used. Thus, there is no need to separate the various plastics. Scrap plastic as a filler has many potential uses. In particular, it might be used advantageously in thermoset materials such as epoxy and polyester resins. Plastic filler also could be incorporated in both rigid and flexible polyurethanes. Generally, adding scrap plastic into foamed plastic products can improve the rigidity of the foam and, in certain instances, it can be used advantageously to modify the density of the foamed product.

Multiplastics. As indicated in Part I, reprocessing mixtures of different plastics normally produce products with poor physical properties; they are often cheesy and brittle in nature. Recently, Dow Chemical[36] reported that chlorinated polyethylene (CPE) can be used as a compatibilizer for the reclamation of these mixtures of plastic materials. Apparently, adding CPE to a blend of resins can yield a material with useful properties. In the Dow study, they collected 100 pounds of scrap plastic from a land-fill. After it was cleaned, the scrap was used as the raw material. It contained 63 percent polyethylene, 31 percent polystyrene, and about 6 percent PVC and other resins. Various amounts of CPE were added to this mixture, and the physical properties of the compression-molded samples were measured. The results are shown in Table 50. Apparently, the optimum CPE level for this mixture is between 23 and 25 percent. This level yields a product that has double the elongation of the control, and the tensile and impact strengths are also improved.

The properties of the final product made with CPE vary with the nature of the scrap and the concentration of CPE; within certain limits, the properties of the end-product also can be varied by including some virgin resin. Applications for this type of product are varied, from tile, plastic pallets, and toys to articles of construction. CPE is relatively expensive as compared to the ''big five'' resins, and its cost has to be considered in the economics of any possible application, although a cheaper product might be possible based on scrap polyethylene. Dow has only carried out a limited study; commercialization of this process is still farther down the road.

The Construction Market. Many of the products described above, whether mono, multiplastics, or composites, are potentially useful in the building and construction field. As mentioned in Part II, building and construction is the largest market today for plastic materials. In many applications, plastics are closely combined with traditional materials in walls, roofs, floors, ceilings, and other building elements; furthermore, plastics will continue to make inroads in the building industry as materials in their own right and not as replacements. The great emphasis today on prefinished products that require less skilled labor at the construction site is one of the factors that will promote the increasing consumption of plastic

TABLE 50

PHYSICAL PROPERTIES OF ACTUAL PLASTIC SCRAP WITH INCREASING LEVELS OF CPE* (COMPRESSION MOLDED SAMPLES)†

	Elongation (%)	Tensile (psi)	Tensile Impact (ft. lb/in)
100% scrap plastic mix	11	1450	0
15% CPE/85% scrap plastic mix	11.7	1715	0.45
17.5% CPE/82.5% scrap plastic mix	12.7	1690	0.54
20% CPE/80% scrap plastic mix	15.7	1715	0.76
22.5% CPE/77.5% scrap plastic mix	17.7	1712	1.5
25% CPE/75% scrap plastic mix	20	1600	1.6
27.5% CPE/72.5% scrap plastic mix	22	1600	2.83

* Chlorinated polyethylene.

† Source: Reference 36

products in this field. New construction materials, whether based on virgin or scrap plastics, will be judged and accepted, according to their ability to meet cost and performance requirements. Where they have these advantages, such as in plumbing systems where installed cost savings compared with metal pipe can be as much as 50 percent, they will take a larger share of the market. In contrast, where their cost is relatively high, such as with PVC siding, their penetration of the market will remain limited.

Plastics today are used in many ways in building construction. For example, they are used in sandwich systems for walls, floors, and ceilings, and they are used in roofing systems not only to improve insulation but as an integral part of the structure. Plastics are found in both exterior and interior building finishes and as secondary building elements such as in windows, where PVC is used for the frames and weatherstripping. PVC also is used in doors, gutters, and downspouts; shutters and hardware utilize PVC, nylon, and ABS. All of these applications are attractive markets for secondary resins.

Miscellaneous. Some of the more far-out applications for scrap plastic uncovered in our interviewing included the use of scrap for artificial snow and as animal feed. Dow[37] reported that low-density polyethylene pellets (this could include clean scrap) in cattle diets have successfully replaced roughage. This synthetic roughage has been patented by Farmland Industries, a Kansas City Co-op.

Another interesting use for scrap plastic and rubber was mentioned in U.S. Patent 3,567,660. This patent describes a process for absorbing oil from oil spills using a mixture of shredded rubber tires and particulate polystyrene scrap. The resulting conglomerate can then be converted to an asphalt-like material. The rubber and polystyrene are used in ratios from 10:1 to 1:10, depending on the kind of oil to be cleaned up (light oil requires more polystyrene than does heavy oil). To date, this process only has been tested in the laboratory. The inventor, Dr. Winkler, estimates the cost of the oil sorbent in quantity at $40 to $45 per ton, including transportation to the site of use. In comparison, straw, which is a widely used oil absorbent, costs $25 to $30 per ton.

Tertiary Recycling

Pyrolysis. One of the best examples of tertiary recycling is the reclamation of scrap plastics by pyrolysis. Pyrolysis differs from destructive distillation in that almost the entire pyrolyzate is recovered as a non-distillable melt. According to Potts[38] of Union Carbide, Carbide has developed technology for converting thermoplastic resins on a continuous basis into wax-like solids, greases, or liquids as desired. Further cracking into gases for use as fuel or as organic raw materials also is feasible. He has shown that it is possible to pyrolyze many plastics, including polyolefins, PVC, polystyrene, and their copolymers--both individually and in blends.

Scrap plastic generated by the industry can be used as a raw material for this process, but the process also is applicable to a mixed plastic stream that could be separated from municipal wastes. In using such a mixture containing PVC, the extruder unit designed for this type of pyrolysis can include a vented section to remove the evolved hydrogen chloride. The unit also can be used to remove other volatiles such as plasticizers.

In chemical composition, the plastic pyrolyzate is somewhat like petroleum, with certain outstanding differences in the types of organic molecules present. For example, the pyrolyzates contain no sulfur compounds and little of the high-molecular-weight hydrocarbons. Carbide, however, has not done extensive application work on these pyrolysis products, although they have patented some products manufactured by the pyrolysis of polyethylene; among them, paste waxes, polishes, printing inks, lubricants, textile finishing agents, and adhesives. Other possible applications include upgrading asphalt compositions for heavy-duty service, an agricultural mulch, and perhaps the pyrolyzate can even be used as a carbon source for the synthesis of proteins by micro-organisms.

Because applications for the products of pyrolysis are not well known, the question of the economics of this process remains unanswered at this time. Some[39] have estimated that pyrolysis would cost about 10 percent that of incineration, assuming credits for the sale of pyrolysis products, but without taking into consideration the problems of collection of the solid waste raw material and the sale and distribution of the end products. Lederman[40] pointed out that mixed olefins are valued at about 1.5 cents per pound today, and if the pyrolysis plant was designed to make this type of products, a plant to handle 15 million pounds per year of polyolefin waste would require an investment of about $500,000. Therefore, according to his estimates, the pyrolysis operation would show only a modest return for this small production volume.

As a method of disposing of total municipal combustible refuse, i.e., plastics plus other organics, pyrolysis is a technically feasible and viable process, but at best it represents a marginal venture opportunity for an industrial firm.[41] However, this process would appear to offer an attractive possibility to municipalities, because they do not have to meet private return on investment criteria. When the pyrolysis products are taken at fuel value, economic analyses indicate that at zero expected return, refuse disposal costs are negligible.

Energy Conversion. Steam-raising incineration is another form of tertiary recycling. Although relatively new in North America, these incinerators have been operating in Europe for some time. The incinerator in Montreal was the first to be built in North America. It is capable of processing 1200 tons of municipal refuse per day, and more recently a similar incinerator has been constructed in Chicago. The Chicago facility has a capacity of 1600 tons of refuse per day. The total cost of the Montreal plant was about $15 million and, according to W. J. Orr, Montreal's engineer,[42] it costs Montreal $7 to dispose of 1 ton of refuse, including capital expenditures. When the sale of steam is well established, Orr predicts that costs will drop to $3.50 per ton. This credit is equal to approximately 2/10 cent for each pound of refuse converted to steam. If pure polyolefin plastic scrap was burned for fuel value, it would have a value of about 0.5 cents per pound. This is based on fuel being valued at 25 cents per million Btu.

Under the financial backing of the Environmental Protection Agency, Combustion Power Co., Inc., (Menlo Park, California) has been operating a prototype incinerator-generator called the CPU-400. This unit can consume 400 tons of solid waste per day and produce 15,000 kilowatts of electricity. Disposal costs with this unit amount to $1.20 per ton.[43]

Thus, energy conversion is a viable alternative application for scrap plastic, but compared to those applications based on using scrap plastic as a plastic, energy conversion offers only a relatively low return--0.5 cents per pound as compared to 3 to 6 cents per pound when it is used as a raw material in the production of plastics. However, the energy conversion process has the advantage that it can easily use mixtures of plastics.

Other Conversions. In a study for the Public Health Service (now EPA) to investigate the utilization of scrap plastics for the production of high-volume process chemicals, Ottinger[44] reported that the thermal decomposition of polystyrene, PVC, and mixed plastics was technically the most attractive recovery process. Ottinger used mathematical models only, experimental work was not part of the initial analysis. He found that the recovery of hydrogen chloride from the combustion of polyvinylchloride was economically feasible for mixtures containing more than 75 percent polyvinylchloride. Another possibility was the generation of styrene monomer by the thermal decomposition of polystyrene.

Jensen[12] also recommended PVC as a commercial source of HCl or hydrochloric acid. One ton of PVC recovered from urban waste is a potential source of 1,000 pounds of HCl which, in turn, is convertible to 3,000 pounds of hydrochloric acid when combined with water. This could have advantages for the consumer of HCl in outlying regions, because this process reduces the hazard in shipping and storing pure HCl and also lowers the cost of shipping. For example, scrap PVC could be shipped by railcar, stored in bins, and decomposed when HCl was needed at the users site. According to Jensen's analysis, per pound of HCl, shipment as PVC appears to cost less than half the rate as the acid, using the freight rates quoted for Southwestern United States.

Present State of the Art

Many of the new applications for secondary resins discussed above need further development before they can be considered a commercial operation, except for the well-developed products that are currently being marketed. A few resin companies today are carrying out research to explore new applications for scrap plastics; others are waiting on the sidelines for new applications to develop. We believe that applications research of this type can be a fruitful area for new research.

RECYCLING PROGRAMS

As noted in Part III, the concentration of plastics in the typical municipal disposal site is seldom on the average greater than 5 weight percent and, in most instances, it is considerably less. Furthermore, the plastics are normally present as mixtures. Thus, at the present time, separation at the final disposal site is extremely unattractive both technically and economically; whereas, separation of some plastics during intermediate disposal either at a collection center or in the home becomes essential if recycling of plastics is to be promoted. Thus, recovery of plastic wastes from the consumer must inevitably involve some form of interception of these wastes before they reach the ultimate disposal site. Interception is an attractive strategy today whether the material is plastic, glass, paper, or metal because:

(1) Economies in recycling and reuse of certain materials may be achieved through segregated collection, which eliminates the cost of separating a material once it is mixed with other wastes;

(2) Where municipal facilities are only designed for a non-reclamatory type operation (and most facilities are of this type), interception provides the only means for recovering materials that may have salvage values;

(3) Programs of interception, when sponsored by a consumer-oriented industry have a certain value in promoting the public image of a firm as responsive to environmental values;

(4) Interception may be selectively mandated for certain materials deemed to be environmentally more damaging than others, when disposed of in the traditional fashion.

Present programs of interception are highly labor intensive and their success, if any, has been based upon public response. A recent AP survey showed that the collection and recycling of trash is being carried out with increasing frequency in the U.S. today. Efforts range from a city-wide recycling day in New York City to a bi-monthly ''beer can stomp'' at the University of Utah to a black-owned and operated recycling plant in a low-income section of Chicago. In most instances, the consumer transports the spent containers, whether glass or metal, to central collection points where they receive small or no monetary compensation; thus, the cost of assembling the containers for subsequent transport has been limited to the costs associated with advertising the collection program and operating the collection center itself.

To gain an understanding of these collection centers in general, we have summarized below some of the details of the various interception programs. These programs include plastics as well as other materials, because the programs with other materials have been developed more fully.

Plastics

One of the first programs in plastics in the U.S. was started on Earth Day 1970 by the Golden Arrow Dairy in San Diego, California. Golden Arrow delivers milk in half-gallon plastic containers made of high-density polyethylene. The containers are fabricated right in the dairy; the dairy uses approximately 1 million pounds of polyethylene per year. According to Golden Arrow, in-plant fabrication of the all-plastic container costs about 1/2 cent more than the equivalent plastic-coated carton. In spite of the higher cost, this dairy believes that the polyethylene milk container is a better way of packaging milk. It is lightweight, leakproof, easy to open, resealable, warmed at sterilizing temperature, and easy to return.

About 75 percent of their half-gallon plastic containers are used for home delivery. Thus, they have little difficulty in redeeming the bottles, because the delivery man picks up the empty ones when he brings the filled containers. In middle-income neighborhoods, and particularly those near schools, Golden Arrow reported that returns as high as 75 to 80 percent are common. In contrast, in the lower-income neightborhoods, returns tend to be about 20 percent. Overall returns are about 30 percent.

This dairy also delivers to cash and carry stores, where they have set up bins for the empty containers. Here they retrieve about 25 to 30 percent of their plastic containers. However, in supermarkets, where some bins also were installed, only a few percent were returned. In no case does the consumer receive a bounty from the dairy for returning the spent container.

The causes for this difference between the number of returns at the cash and carry store and the supermarket are worth exploring. One explanation may be that the consumer who goes to a cash and carry store, which is primarily a milk store, usually makes a separate trip to purchase his milk, and therefore he often takes the empty bottles with him when he goes to the store. In contrast, the consumer who purchases from a supermarket usually goes there to buy a number of items, and therefore he does not automatically think of taking empty bottles from home.

According to an interview in early 1971, the following process is used: the empty polyethylene bottles that are returned are granulated and washed in a jerry-rigged affair, consisting of a common cement mixer filled partially with water. The scrap is dried, and then it often goes through another grinding operation to reduce the particle size to 1/4 inch diameter. The dairy estimates that this operation costs them about 1 1/2 cents per pound of scrap. As they develop more sophisticated equipment (there is commercial equipment available), the cost could go up to 2 to 2 1/2 cents per pound. The granulated material is sold to reprocessors and fabricators in the Los Angeles area, who pay between 4 and 6 cents per pound.

On this small scale, the operation is probably a breakeven proposition. This dairy has been plagued with many political impediments. First, the local health authorities in the State of California objected to their recycling program because, in their view, the dairy was hauling trash when they hauled empty milk containers. After a few months, they were able to remove this restriction. Next, when they tried to sell their secondary resin to a plastic-pipe manufacturer, they ran into the restrictions of the Soil Conservation Service mentioned in the previous section.

Other dairies have been following this development closely. Another Southern California dairy, Alta-Dena, also has its route man pick up the empty polyethylene bottles. These are granulated at the dairy and sold for the fabrication of toys, irrigation lines, leech lines, and plant pots for nurseries. Again, this dairy is apparently just breaking even, in terms of the economics.

On the other end of the country, Wade Dairy in Connecticut also has a recycling program. In contrast to others, this dairy uses thermoformed individual milk bottles made of impact polystyrene. The dairy delivers to the school, and the containers are returned by the students, granulated, and sold to a local reprocessor for about 6 cents per pound. They are considering the installation of size-reduction equipment on their milk trucks, so that the milk man will be able to return the bottles in granulated form to the collection site. A dairy in Michigan has a similar program.

Recently, a group of boy scouts, sponsored by Owens-Illinois, held a clean-up drive along the banks of the Maumee River in Ohio. The scouts collected 1,300 polyethylene bottles, which were redeemed for 3 to 6 cents per pound by Advanced Drainage of Ohio who recycled the scrap from the plastic bottles into drainage pipe.

In a new experiment, a company has reported that they are attempting to recycle polyethylene bags. This would be unique, because one would think that consumers are more likely to set aside rigid containers than plastic bags in any intermediate disposal site. This program has been launched by Acteson Paper Company of Van Nuys, California, who plan to steam heat, aerate, dry, and repelletize the recovered polyethylene. This program will be worth observing to see if it will be successful.

Some plastic recycling programs also have been set up in Europe during the past two years. For example, a program to collect plastic bottles from the householder has been instituted in Spain, and in Germany a special test collection program was set up with some schools. This program is described in an article by Engel[35]. A number of schools in Berlin participated in the test program together with the municipal refuse department of Berlin and Farbwerke Hoechst. Disposal units for the empty plastic containers used to package a fruit drink were placed in the schoolyard. These were similar to mailboxes, and in this study they experimented with different types of waste disposal units. For example, one was equipped with a special disinfecting solution; it was so designed that when the lid was opened droplets of the disinfectant spread throughout the unit.

In collecting from the disposal unit, they experimented with special suction units that were attached to the refuse truck. These could empty as many as 50 giant containers (approximately 11 cu meters) in one load. The collected polyethylene containers were then granulated at a central collection point; they also considered developing a system where granulators were made part of the suction trucks. Also, in this study a few combination receptacles were constructed for individual household collection. These consisted of a hamper and a roller which has up to 48 plastic bags, and they were designed so that as soon as one bag was full, it could be removed and brought to the collection center.

Aluminum

Scrap aluminum commands a price of $370 per ton (delivered to the smelter), which makes it one of the highest-priced secondary materials currently being recycled in consumer programs. Therefore, the economics of recovery through these programs are more attractive than for other materials. The collection centers maintained by aluminum manufacturers and distributors of products made in aluminum cans redeem the aluminum for $200 per ton. Returns have been good--more than 115 million all-aluminum cans were returned to reclamation centers for recycling in 1970, which represents about 5.5 million pounds or less than 1 percent of the total production of aluminum cans. These cans were collected from 288 collection points in 16 states.

As an indication of the popularity of aluminum can collection, Reynolds Metal Company alone will achieve a collection of 200 million cans in 1971, according to the results at the end of the first half of 1971. This is more than all cans collected in 1970. The year before, Reynolds collected only 80 million cans. Reynolds now has 423 collection centers in 20 states, and they also have a mobile unit complete with magnetic separator, electric scale, and shredding equipment that visits collection points periodically. The collection points are operated for the most part by beverage manufacturers and distributors.

Interestingly, Reynolds has recently added a new collection system whereby the consumers can have their recyclable aluminum collected from their homes. They plan to provide 1,000 test households in Fort Lauderdale, Florida, with plastic bags for the aluminum scrap. These bags will be picked up during the regular garbage collection and sent to a nearby recycling center.

Kaiser Aluminum and Chemical Corporation has recently announced (June 1971) that they are expanding their ''Can Do'' program for recycling aluminum cans from a pilot basis in the San Francisco Bay area to include 36 more cities in central and northern California. The reclaimed cans are transported to a Kaiser aluminum plant in Oakland for sorting and baling and from there to a Kaiser plant in the northwest for melting and recasting into aluminum products.

Alcoa launched its collection program in 1970 in San Diego under the ''Yes, We Can'' slogan. This was followed by a similar program in Dallas and Fort Worth. Collection facilities were provided by distributors, brewers, soft-drink companies, and some major shopping centers. The San Diego program has been particularly effective, and in 1970 about 5 percent of Alcoa's aluminum cans in this city were recycled via the collection center route. The collected cans, in this case, are sold to local scrap dealers who, in turn, ship the material to Indiana for making sheet.

The Adolph Coors Company claims that they alone collected more than 120 million cans during the first 10 months of 1970. Gaining public co-operation has been the major problem according to Coors. Where enthusiasm has been aroused in a particular locality, returns of over 60 percent of the company's cans have resulted. Significantly, Coors noted that these high returns all but eliminated the presence of their aluminum cans in litter.

In spite of the high value for aluminum, the success of the program is still dependent upon the continuous volunteer free labor given to assembling the empty cans for transport. Furthermore, a major continuing cost of these programs appears to be in advertising and public relations. We were unable to obtain detailed information regarding the breakdown of cost between advertising, public relations, physical collection, and transportation costs.

In testimony before the Senate in February 1970, Dr. Robert F. Testin, Director of Environmental Planning for Reynolds, reported that a central collection facility must take in about 32.5 tons of aluminum cans per month to break even. He indicated that the operation in Los Angeles at that time was slightly profitable. It is significant to quote Dr. Testin, who said that ''we are firmly convinced that we have hit upon part of the answer to the problems of recycling litter and solid waste; namely, if you have a material that is sufficiently valuable to make it worthwhile for people to participate, you can recycle more than enough material to make a reclamation center pay its way.''

Steel

The major steel makers, Bethlehem, Jones & Laughlin, Kaiser, National, U.S. Steel, Wheeling-Pittsburgh, and Youngstown Sheet, have established 80 collection points in 39 cities (more are in the works) that will accept all tin plate, tin-free steel and bimetallic cans for remelting. By June of 1971 the can industry expects to have more than 200 reclamation centers collecting aluminum and steel cans. The can industry claims that these recycling programs are costing them money, but they are being expanded because of the threat of restrictive legislation.

The recovered steel cans are either directly recycled into cans or they are recycled by the copper-smelting industry where the melt is used to precipitate copper from low-grade ore. Five companies recover steel at 30 detinning plants; one of the by-products is stannous fluoride for toothpaste.

Glass

The Glass Container Manufacturers Institute (GCMI) has been very aggressive in developing collection centers for glass containers. According to this institute, redemption of used glass containers in recycling programs are expected to reach an annual rate of 1/2 billion jars and bottles by mid-1971. This rate has been increasing rapidly since the program was initiated in July 1970. Payments average 1 cent per pound ($20/ton), and most of the collection centers are established near the manufacturing plants. Ninety-two plants in 25 states are currently participating in this program.

At this time, the economics of glass collection are still not very attractive; and like the can manufacturers, GCMI is using these programs to obtain favorable public exposure. According to GCMI, the actual cost of retrieving scrap glass (cullet) from these interception programs has been $30 to $40 per ton. Transportation to the glass plant is the major cost.

Because collection is highly uneconomical at present, the cullet dealers are turning to non-profit groups for volunteer collection services.

Owens-Illinois operate a glass-mobile program, where a trailer makes the rounds of local supermarkets and collection centers. Interestingly, they found that collection varies considerably depending upon the location. When parked at Paramus, New Jersey, the truck collected 60 tons of glass in five weeks; in the same length of time at nearby Newark barely a single truckload was accumulated during the same period. Paramus is a middle-class municipality, whereas many of Newark's population are less privileged. Experience with the glass mobile program also suggested that green stamps provided a better incentive for glass return than cash does. In New Brunswick when 1/2 cent per bottle was paid in addition to a program of prizes and heavy publicity, 23 tons of cullet were collected in five weeks. In Paramus, however, using trading stamps, 55 tons were collected in the same period, with 30 tons in the fifth week of the program alone.

General

In some instances, bottlers are opening collection centers for glass and metal. For example, in 1971 the Coca-Cola Bottling Company opened 17 collection centers in New York City for both glass bottles and aluminum cans. They pay 1/2 cent per bottle or can, regardless of brand. At the collection centers, the company provides free plastic bags and information booklets explaining how to recognize steel cans from aluminum and the need to separate bottles according to color. The glass is melted at one of the nearby glass plants and the cans are recycled by the Reynolds Metals Company.

Lucky Breweries, Inc., of San Francisco, California, also have a program where they take back steel cans and glass bottles. They pay out 12 cents for every case of 24 steel cans and 25 cents for every case of 24 bottles. Apparently, they were the first U.S. brewer to buy back tin-plate cans.

Recently, a food manufacturer instituted a test program in a small community where collections are made from the home. Various bins were distributed to the householder, who was asked to separate glass and metal containers. These are collected every two weeks. Seventy-five percent of the householders who received the bins participated in this program. This program will be worth watching to see how it compares with the normal collection program from a collection center.

SEPARATION AT THE INTERMEDIATE DISPOSAL SITE

In the previous section, we described some of the current programs for intercepting scrap and nuisance plastics from the consumer before they reach the final disposal site. Interception of scrap plastic from the manufacturer is a well-established technique, as discussed in earlier parts of this report. In most instances scrap plastic that is part of a composite becomes nuisance plastic in converting and fabricating operations. However, some of this composite scrap is intercepted, and the individual materials are recovered by a special segment that is outside of the plastics industry. At this time, this composite scrap is salvaged in order to recover the non-plastic material, because it commands a relatively high price in the marketplace.

Metal Wire Recovery Systems

As noted in Part III, large volumes of scrap are generated by the fabrication of coated wire. When these wastes are combined with those generated by manufacturers who use coated wire as well as that recovered in demolition operations, the volume is sufficient to promote an industry specifically organized to salvage the material. Copper and aluminum are valuable and, traditionally, these were recovered from the insulated wire merely by burning off the insulation. This method not only caused air pollution, but it also produced metal with definite defects due to the oxidation and chlorination reactions that occurred during the burning process.

To avoid these problems, the industry developed a mechanical separation technique. One of the first examples of mechanical separation of the insulation from the metal occurred in 1942. At this time, rubber was the major insulating material, and because of the war the government was interested in its recovery. The separation was carried out by first chopping the wire scrap so that it was fine enough to pass through a small diameter screen. After chopping, the separation of the metal from the rubber was carried out on an air table or specific-gravity separator. This is essentially the process that is used today; of course, many improvements and modifications have been made since that time.

The metal reclaiming operation varies somewhat depending upon the form in which the material is available.[45] If the wire diameter varies from 1/4 inch to 2 or 3 inches, then a 1 to 1 1/2 inch screen is used at the bottom of the granulator. On the other hand, if the source of the scrap material is from electronic or telephone equipment, it is very fine and is usually insulated with polyethylene; in this instance, a 1/2 inch diameter screen is used.

A typical specific-gravity separator consists of an uphill conveyor with the end away from the feed being elevated. The conveyor has a porous surface through which air is carefully introduced. The chopped wire moves along this conveyor and, due to the different specific gravities of the metal and plastic, stratification occurs. The lighter plastic particles are lifted out of the uphill conveyance, while the heavier metal particles usually remain on the conveyor. When the coarser diameter wire is used, the recovery of metal is between 99 and 99 1/2 percent. With the coarser metal wire, some of the very fine particles of copper or aluminum become smeared into the plastic and with the fine wire, some small flat pieces of the chopped material come through the process with the insulation intact. Generally, in the metal recovery process, no more than 1/2 percent of the plastic is left with the copper. Jarman[45] estimates that it costs $12.50 to process a ton of scrap by this separation technique.

Most of the recovered insulating materials, which are primarily PVC and polyethylene, end up as land fill today. Companies using this separation process have been looking for applications for this scrap plastic. One company tried to use it as a filler for flexible polyurethanes, but the metal impurities caused difficulties. Others have used it as a molding material in a low pressure injection molding machine. Some of these scrap generating companies also have the option of segregating the insulated wire according to the type of plastic, if the overall economics are right.

Separation of Plastic from Plastic-Coated Paper and Paperboard

Plastic-coated board and paper scrap is available in large quantities from fabrication and converting operations, as noted in Part III. As much as 80 percent of this scrap is salvaged and reprocessed today. However, only the pulp is recovered and reused. For the most part, the plastic (polyethylene), which amounts to 8 to 12 percent of the scrap, is either incinerated or used in land fill.

Most reprocessors use a hydropulper to separate the plastic from the paper. The hydropulper is essentially a large tank with a screened bottom. Inside, it is equipped with heavy rotor blades attached to the base of the tank. These can chew up the scrap material that is suspended in water. In this process, polyethylene is removed from the backing paperboard as it is subjected to the high shear forces of the hydropulper at temperatures of 100 to 120 F. The pulp that separates is then extracted through the perforated (1/2 in. diameter) bottom plate of the hydropulper. The plastic usually accumulates in sheet form and, therefore, does not go through the perforated plate. It is removed from the hydropulper periodically.

The paper fiber recovered from this operation is of very high quality and is readily sold. It commands a price of between $110 and $125 per ton. The polyethylene in this process undergoes minimal degradation, and it also is a high quality material. Unfortunately, it is contaminated with 1 to 2 percent fiber, which makes recycling of this material more difficult.

PVC-coated papers can be recovered in a similar way, but the coating separates in a stringlike form, and entrains approximately 10 percent of the fiber. Other types of coating such as Saran, cellophane, varnish, or latex are not easily separated by this method of disintegration. Chemical additives and high temperatures are required. Containers that have been printed with multi-colored inks are reclaimed in the hydropulper process by using approximately 5 percent sodium hydroxide in the warm water to disperse the ink. Usually an auxiliary washing stage is then added to the pulp treatment to remove the ink and any unexhausted chemicals.

Another separation process for this type scrap was developed by Riverside Paper Corporation. This is the ''Polysolv'' system, which uses a solvent such as trichloroethylene to remove the various coatings. This solvent removes not only polyethylene and PVC, but it can remove polyvinylacetate, polypropylene, and wax. Generally, the scrap material is subjected to multiple batch washes in a pressurized rotary reactor, and the trichloroethylene is recycled. On completion of the washing and drying cycle, the board is recovered in the same physical form it entered the process, except that the coating is absent.

This process easily removes the ink in the coatings leaving the reclaimed fiber essentially ink free; however, the polyethylene is considerably degraded. With some modifications, the polyethylene could be recovered essentially 100 percent pure with no fiber contamination, if a satisfactory market were available.

A number of paper companies use the hydropulper separation system, therefore, this polyethylene scrap is readily available if applications are found. The scrap is purchased for about $40 per ton; process costs are approximately $35 per ton, baling about $5 per ton, and transportation is about $5 per ton, which results in an $85-per-ton cost. As mentioned above, the pulp is then sold for $110 to $125 per ton.

SEPARATION AT THE FINAL DISPOSAL SITE

At the present time, a system for isolating plastics from the total solid waste stream at the final disposal site is not available, and if it were the economics would undoubtedly be unattractive, as mentioned earlier. On the other hand, some separation systems have been developed for materials such as paper, metal, and glass. Therefore, once these waste materials have been removed, the possibility of isolating plastics is improved; nevertheless, with the economic restraints, the technology is still a long way off.

Separation of Plastics

The Bureau of Mines at College Park, Maryland, has apparently developed a proprietary process for separating solid wastes into an enriched bulk plastic stream and then separating this into groups of different plastics. Because of the patent situation, the Bureau is not releasing details at the present time. According to one report, their process is able to separate plastics and yet leave the plastic-coated paper with the remainder of the waste stream.

Jensen,[12] in his study, separated the ‘‘big five’’ plastics into clean fractions from an initial mixture containing high and low density polyethylenes, polypropylene, polystyrene and PVC. He used a gravity separation technique similar to that used for minerals. The density of these plastics ranges from 0.901 to 1.313 g per cc for polypropylene and PVC, respectively.

The separation is carried out as follows. Water separates the polystyrene and PVC from the other three plastics, and these two plastics are then divided in an aqueous calcium chloride solution with a specific gravity of 1.28 g per cc, which floats the polystyrene away from the PVC. Alcohol-water solutions are used to further separate the fraction that floated on water. A 50/50 solution with a specific gravity of 0.93 floats the LDPE and polypropylene away from the HDPE, and these two components, LDPE and polypropylene, are separated in a solution containing 60 parts alcohol and 40 parts water. As one can see, the separation of various plastics from a mix, though technically feasible, is not really a viable economic process.

Separation of Other Materials

Gross separation of the valuable components from mixed refuse has taken place at incinerators and land-fill operations for many years. In some cases, a degree of mechanization has been introdcued where the feed to an incinerator proceeds on a conveyer belt, and ‘‘picking stations’’ with hoppers going down to baling presses are arranged along the belt so that one man can remove clean newspapers, another corrugated cardboard, and so on. At another point a magnet removes ferrous components. The largest operation of this type is that of the Lone Star Organics Plant of Metropolitan Waste Conversion Corporation in Houston, Texas.

Wilson[46] has pointed out that this type of hand sorting can be easily designed for coding and mechanical switching systems. For example, coding is used today for automatic post-office sorting and for airport-baggage handling, and such systems could be devised for handling solid wastes. Thus, quoting Wilson,

> ‘‘the refuse would be fed onto a moving belt, a magnet would remove ferrous material for baling, and a vibrating sieve would then allow all pieces smaller than a certain size to drop away for disposal. The remaining large items would then be fed to a fast-moving belt in such a way that each item is

> separated from the next by an empty space on the belt. This belt would pass in view of an operator at a coding station who would have before him a console having buttons, one for each component of refuse to be sorted. By pressing, an appropriate button, as each piece of refuse appeared, he would code a magnetic 'stripe' on the underside of the belt or on a magnetic tape geared to the belt. If the code indicated 'glass', the coding would actuate an appropriate diverter to sweep the glass into a hopper.''

In this way the productivity of the human sorter is increased five to ten times by this mechanical assistance. But this system applied to municipal disposal is many years away.

Air-Classification Systems. One of the more widely publicized separation systems is the air classification system engineered by Stanford Research Institute (SRI). In this system, refuse is first shredded to a uniform size and dried (cost: \$0.20 per ton) and then sorted by pressurzied air flowing upward through a zig-zag channel. The refuse is fed into the channel at an intermediate point. Pieces with a combination of low density and high drag are entrained into the rising air stream, while the heavier or lower-drag pieces descend. SRI claims that components having densities only a few percent apart can be successfully and economically sorted by this technique. In this way, SRI separates solid rubber, glass, metal, stone, foam rubber, foam plastic, corrugated and paperboard paper, and plastic film. Further segregation is possible by using a magnet or other means (cost: \$0.10 per ton). The estimated capital investment for this piece of equipment is \$5,000 or less per ton of capacity.

The Warren Spring Ministry of Technology Laboratory in Britain has adapted a fluidized bed separator for pulverized refuse. In this process, air is supplied to several sections of a vibrating porous bronze table. A size-selected fluidizing medium, in this case ferrosilicone or magnetic or iron powder, is kept in suspension and recirculated. The feed particles are larger than those of the medium so that filtering can be used. The denser particles which sink to the bottom of the bed are moved by the vibrating table up the bed, while the lighter feed particles float downward along the top of the bed. This unit resembles the one described above for separating insulation from the metal in coated wire. Operating costs for 25 cents to 50 cents per ton have been forecast, including depreciation. The Bureau of Mines in this country has put together a similar repetitive screening/pulverizing/screening system that automatically sorts incinerator residues in progressive stages.

Black Clawson Process. In still another approach, under a grant from the Environmental Protection Agency, refuse is separated by a wet process. This system, developed by Black Clawson, uses existing equipment and provides for the salvage of usable fiber, glass, and metal. The process operates as follows: solid waste from a packer truck is discharged onto an apron conveyor from which it is fed into the hydropulper described in the previous section. The hydropulper is the heart of the system. In it, all pulpable, grindable, and fryable materials such as food waste, plastic, paper, rubber, rags, glass, leaves, etc., are mixed with water and are disintegrated by the rotor. Materials in the water slurry are removed selectively by an internal screen. Large metallic objects that do not disintegrate are ejected from the hydropulper and are continuously removed by the ‘‘junk remover.’’ Other than these large metallic pieces, everything is reduced to 1/4 to 3/4 in. flake, which goes out through the extraction holes on the bottom of the hydropulper.

The slurry is then pumped to a liquid cyclone where the heavier items are separated and removed: paper fiber goes through the holes in the screen, and glass and metal remain behind. In this operation, glass separates with aluminum. Typically, the glass is in the form of 1/4 to 1/2 in. chips and is usable cullet. Black Clawson plans to use an air separation system for separating the aluminum from glass. Up to this point, 45 percent of the material has been separated.

The next step, which involves extracting the paper fiber, is called ‘‘Fibre Claim.’’ In this process, the slurry remaining after the glass, sand, and metal have been removed is further cleaned in high-efficiency centrifugal cleaners. The slurry is then introduced into a primary fiber selector. This selectivity removes most of the valuable long fine fiber, which is dewatered and baled. The reject from the primary selector, which is intermediate-length fibers and other organic materials, is introduced into a secondary fiber selector where the intermediate-length fibers are removed, and similarly dewatered, and baled. Up to this point, the cycle time is about 90 minutes and 35 percent of the feed remains unseparated. This fraction is primarily organic in composition. It contains some of the wet-strength paper fiber, textiles, leather, plastics, etc.

Black Clawson claims that by additional screening of this organic fraction, if desired, they can separate the very fine fiber and some of the organic residue from food waste to give a fraction which represents approximately 5 percent of the total solid waste stream. Most of the plastic wastes would be found in this fraction. Because this fraction would be highly enriched with plastic wastes, an economic separation of a mixture of plastics may be feasible. However, at the present time, this organic fraction is burned in a fluid-bed incinerator.

Black Clawson will have a full-size plant in operation utilizing this process sometime during 1971 in Franklin, Ohio. This plant will have a 150-ton capacity and will cost $1.75 million. They estimate that the net processing costs for this plant will be $6.00 per ton. This is taking credits for the various items that they can separate. On the basis of a 150-ton-day capacity, the Franklin plant will turn out 30 tons of paper fiber worth $750, 12 tons of ferrous metal worth $96, and 12 tons of glass cullet worth $144. The operating cost for a facility capable of handling 1,000 tons per day (3 shifts) would be $7.55 per ton. This is based on amortization (25 years at 6%) of a $10 million plant. If that which is salvagable from this plant can be sold, the total credit could amount to as much as $7.00 per ton, which is almost equivalent to the operating cost.

Miscellaneous Systems. Looking farther down the road, MIT is working on several concepts. One is an inverted cone vortex chamber that reduces the size of waste articles by means of cutters mounted in the chamber walls. The materials are then classified by specific gravity. Another concept uses a pinpoint laser beam that identifies waste materials that are in granulated form by immediate spectographic and/or gas chromatographic analysis. Once identified, the wastes are sorted automatically by selective switching.

PART V

TACTICS AND STRATEGIES FOR RECYCLING PLASTICS

OBJECTIVES

In developing strategies and examining alternative solutions to promoting the recycling of plastics, the following objectives were developed as criteria: (1) minimize environmental damage; (2) maximize the pound-volume of troublesome nuisance plastics recycled and/or reused as a percentage of total plastics production; (3) minimize the pound-volume yield of troublesome nuisance plastics as a percentage of total plastics production; (4) minimize the sum cost of achieving objectives 1, 2, and 3; (5) minimize economic disruption; (6) minimize disposal costs; (7) maximize the recyclability of plastics. To conserve natural resources also was considered as a separate objective, but this is already implied by objectives 2 and 3. Each of these objectives can be considered specifications necessary to maximize economic efficiency and well being within the plastics cycle.

Objective 1--Minimize Environmental Damage

Objective 1 is the primary objective, and the interest in promoting recycling follows. The major concern of this study is to minimize those aspects of disposing of spent plastic products that tend to make the environment less desirable to society. There are two aspects to this damage: an economic aspect and an aesthetic one. Neither of these is easily measured, and the latter is essentially subjective.

As an example of economic damage, consider that caused by burning plastics in facilities not specifically designed for this operation. This can increase the maintenance costs involved in operating an incinerator, and in some instances, improper burning can damage public health. Or consider the damage in terms of the actual costs incurred by the disposal of low bulk density rigid plastic containers. For example, this can increase the costs of disposal by increasing the need for more household garbage cans and more collection time.

The best example of the aesthetic aspect of damage is litter. Apparently, certain types of litter are worse than others. For example, consider the following two plastic packaging items as litter--a piece of transparent plastic film and a large opaque rigid plastic container. Obviously the latter is the most visible and, therefore, most people would consider it aesthetically displeasing. However, the same container sitting in one's backyard is considered less damaging to the environment than the container along the roadside. This illustrates the importance of the degree of exposure. Thus, the greater the visibility of the litter and the larger the population exposed to it, the greater the environmental damage.

As another example of the importance of the degree of exposure, consider the open burning of plastic in an area with little or no population. This would be far less damaging than open burning in a densely populated area, where air pollution already is a significant problem.

As these few examples illustrate, incidents of environmental damage range from those that are well defined and directly measurable to those that are highly intangible. Under these circumstances, tradeoffs between alternative types of damage are extremely difficult to make, because not only economic but social, health, and political issues also are involved. For example, it is not clear whether a 10 percent increase of that portion of air pollution which is caused by burning plastics is more or less damaging than a 5 percent increase of a portion of plastics in an open town dump.

Another alternative that was considered in defining environmental damage was to measure it in terms of the cost of removing it. However, this alternative was discarded because it has two undesirable properties: (1) it requires the definition of a normal or ''ideal'' state of the environment, which again would have to be based largely on subjective judgment; (2) damages cannot always be assessed by costs alone. For example, how can one estimate the damage costs if a portion of the population was poisoned due to pollution.

Accordingly, we have assessed environmental damage primarily by noting changes in the characteristics of any of the flows of nuisance plastics into the disposal areas shown in Figure 26 (Part III). For instance, an increase in the volume of one of these flows with no change of the others will generally result in an increase of environmental damage. Similarly, given that the volumes of all flows into disposal areas are held constant, a change in the mix or form in which nuisance plastics are disposed of can increase or decrease environmental damage. For example, if an increasing proportion of the total volume of NP is burned in inadequate incinerators, rather than disposed of in town dumps, environmental damage may be increased.

Objective 2--Maximize The Pound-Volume of Recycle of Troublesome NP

The term ''troublesome'' nuisance plastics refers to those plastics which cannot be easily disposed of either technically and/or economically without significantly increasing environmental damage. To understand the implications of this objective, let ''A'' represent the volume of total plastics production, ''B'' the volume recycled and/or reused. Under steady conditions (or in the long run) the balance of these flows must be preserved. This implies that the volume of flow and all flows leading into the final disposal area cannot be greater than the volume of flow A (the total production), provided that there is no long term buildup in the intermediate disposal area. Thus, by increasing the proportion of flow A that ends up as flow B, the proportion of flow A ending in the final disposal area is decreased. As mentioned above, a decrease of the volume of all flows ending in the final disposal area will decrease environmental damage, unless there is a simultaneous change in other characteristics of these flows that will tend to increase the damage.

Objective 3--Minimize Pound-Volume Yield of Troublesome NP

Whereas objective 2 considers the volume of flow, objective 3 is concerned with the characteristics of the mix of this flow. By reducing the proportion of troublesome components of the total production volume (flow A), a higher proportion of flow A can be recycled and/or reused without affecting the recycling costs. The decrease in the proportion of troublesome NP in the total production of plastics, of course, is of little value unless it affects either the proportion recycled and reused or the costs associated with these processes.

Objective 4--Minimize Costs of Achieving 1, 2, and 3

The costs considered in this objective are primarily ''social'' and administrative costs and not those incurred by manufacturers and distributors in the plastics cycle. Eventually, the consumer will most likely have to pay for a large proportion of the bill for any improvement in the environment; these costs will most likely be reflected either by an increase in the price of plastics or by a tax or both.

Objective 5--Minimize Economic Disruption

The degree of economic disruption implied by this objective is measured by such costs incurred by manufacturers and distributors in replacing current materials, facilities, and processes. These costs also include the costs to society of transitory increases in unemployment and labor market disruptions. But these costs are considered more desirable in view of the objectives listed above. Ultimately, these costs also will be borne by the consumer.

Economic disruption, as defined here, can be caused by any changes in the characteristics of all flows in the entire plastics cycle, excluding the consumer and disposer; both the volumes of these individual flows and the nature of the mix of plastic components are important. Whereas the objectives mentioned above all favor a change of the status quo, objective 5 favors the present state of the system. Accordingly, if no economic disruption is allowed, chances for decreasing environmental damage are small.

Objective 6--Minimize Disposal Costs

This objective is included in our study because all plastics cannot be recycled and/or reused. Therefore, those that remain should be disposed of at minimal cost. These disposal costs include all costs caused by NP, which depend upon the characteristics of the various flows to the ultimate disposal area. For example, if the NP is disposed of in a landfill, the high bulk density NP would be preferred.

Objective 7--Maximize Recyclability Characteristics

The recyclability of a plastic product depends on the chemical, physical, and functional properties of that product. To be recyclable, a product must be reprocessable. As indicated in Part I, chemical properties influence the reprocessability of plastics, and the physical form, such as whether it is a mono, multiplastic, or composite, obviously affects reprocessability.

But, recyclability also depends on how easily the product is collected. As indicated in previous sections, effective recycling of plastics will require interception or collection at the source (the consumer or the manufacturer). Generally, NP in the form of a rigid container is more easily separated and collected by the householder than NP in the form of plastic film. The householder, for example, usually considers film in the same way as paper wrapping and discards it in the trash can. In contrast, the rigid container is often set aside. It is easily segregated from the household refuse, and in the past many containers were set aside for return to the store.

METHOD OF EVALUATING TACTICS AND STRATEGIES

The most basic way of comparing any two strategies involves some measurement of their impact. Unfortunately, many of the objectives listed above cannot be put in quantitative terms, and with some that can, cost information is presently unavailable. For example, the two objectives which are reasonably well defined in terms of measurable quantities are objectives 2 and 3. The ambiguity of the meaning of ''troublesome'' plastics is the only attribute preventing these objectives from being directly and quantitatively measurable. Objectives 6 and 7 are less well defined but are not as vague as objectives 1, 4, and 5. Therefore, in this study it was not possible to measure the overall effectiveness of alternative tactics in any quantitative way; we relied largely on the judgments of our strategy panel. The strategy panel consisted of an economist, a market analyst familiar with the plastics industry, a chemical engineer familiar with plastic fabrication, a polymer chemist, and an operations research analyst. A discussion of the measurement problem in evaluating strategies and tactics developed in this study appears in the Appendix.

In evaluating any particular tactic, we first subjectively rated the tactic according to its impact on objectives 3 and 7, which are the only independent ones in the entire set. Next, we considered objective 2, and in so doing we considered the indirect impact of objectives 3 and 7 on 2. Because objective 6 is affected by objectives 2, 3, and 7, we then evaluated the strategy in terms of its direct impact on objective 6. Objectives 1, 4, and 5, are directly or indirectly affected by all other objectives, and these were used in our final evaluation but in no preferred order.

ASSUMPTIONS MADE IN DEVELOPING A STRATEGY

Before considering strategies and tactics, it is essential to examine an implicit premise and some of the basic findings developed in our research prior to outlining a course of action. Questions had to be answered related to what realistically could be recycled, and what would be the best way of handling the nonrecycled plastics. As indicated previously, for many reasons, primarily technical and economic, not all plastics can be recycled.

An Alternative--No Recycling

First, we considered the alternative of no recycling. As mentioned above, the primary objective is to reduce environmental damage. Promoting the recycling of spent plastic products appears attractive primarily because it reduces the total volume of plastic products in the disposal area. Presumably, this reduction in volume reduces the environmental damage caused by plastics. However, from a purely economic viewpoint, the choice to recycle plastic products is not an entirely obvious choice.

There are really three basic alternatives: (1) accept environmental damage; (2) reduce environmental damage by disposing of plastic products more effectively; (3) reduce environmental damge by promoting recycling. To eliminate the first alternative implies that the social cost of additional environmental damage by NP is greater than the cost of more effective disposal methods and also greater than the cost of recycling. This is an implicit premise of our recommended course of action. Thus, in developing tactics, we assumed that the cost to society of failing to clean up the environment is greater than the clean up costs. In other words, no matter how much it would cost to dispose of nuisance plastic with minimal environmental damage (based on current technology and consumer motivation), from society's view, at any point in the damage reduction process the cost of doing nothing is, say, one dollar greater. According to such a definition, the cost of environmental damage may be treated operationally as infinite. Clearly at some point this assumption must be re-evaluated, when the costs of clean up and damage can be more accurately determined.

While we have developed tactics under this assumption, it is important to emphasize that it is only an assumption. Furthermore, we have not been asked nor have we collected any scientific evidence that would tend to validate the assumption that the cost in terms of environmental damage of nuisance plastic is greater than its effective disposal. In this study, we have also assumed that the social cost of effective disposal of a potentially recyclable plastic product is considerably higher than the cost of recycling.

Strategies Must Apply to All Materials

Another fundamental finding of our research concerns the systematic interdependencies in our ecological and economic systems. These interdependencies make any piecemeal action inefficient and potentially harmful. Discouraging the use of any one substance (e.g., virgin plastics) may merely transfer pollution from one source to another. This need implies that certain strategies developed for promoting recycling of wastes must include all materials (plastics, glass, metal, paper, etc.). Strategies for one material cannot be considered in isolation; otherwise, they will be unsuccessful because one material will be substituted for another and, if substitution occurs, it will not necessarily minimize environmental damage. For example, a high tax discouraging the use of plastics for milk bottles may merely substitute glass and paper refuse for the plastics refuse and not necessarily make any contribution toward reducing total environmental damage.[47] Therefore, many incentive plans must include all materials. On the other hand, to promote the recycling of a product such as a tire does not imply this same consideration, unless a substitute product exists. But, if the product is a glass bottle, then of course, substitutes such as metal cans and plastic containers must be considered in the strategy.

Because of these considerations, we have often outlined below general tactics that can be applied to all materials and not plastics alone. However, because the scope of this study was restricted to developing information for plastics alone, we can only judge the impact of the recommended strategy on the plastics industry. Similar studies of other materials would be needed to determine the overall impact of any tactic that applies to all materials.

Strategies Must Include the Disposal of Nonrecycled Plastics

Because it is not feasible to recycle all plastic products, we have attempted to answer the question of which products should and which products should not be recycled. Thus, a strategy for promoting the recycling of plastics must obviously also consider the strategy for minimizing the environmental damage caused by disposing of plastics that are not easily recycled.

Although rigid containers are potentially recyclable; this only refers to those that are monoplastic. We believe that a composite or multiplastic rigid container that cannot be recycled is normally more damaging to the environment than, say, a plastic bag or flexible plastic packaging in general; these items are more difficult to recycle, because they are not easily collected.

Therefore, in designing a strategy for plastics that can be recycled and those that cannot, we recognized that the characteristics of these two types of plastics need not be the same. Thus, if a plastic article is not designed for recycling, there is no need for it to be a monoplastic; its bulk density is more significant. Conversely, if a plastic product is designed for recycling, its bulk density is not significant.

In most instances the cost of collecting scrap plastic from the consumer will probably be higher than if the scrap were collected directly from the industrial sector. To the extent that the consumer lends his free labor to separating and transporting spent containers to a collection point, the difference between these costs can be narrowed.

IMPEDIMENTS TO RECYCLING

Four major impediments to recycling that have been continuously mentioned throughout this study can be characterized as: economic, political, psychological, and technical. As clearly brought out in Parts II and III, the key one is economic. Secondary resins compete with off-grade virgin resins, and today the difference in selling price between these two is often virtually zero, and in many cases no more than 1 to 2 cents per pound. Therefore, strategies designed to promote the use of secondary materials obviously must be directed at widening the gap in prices between these competitive materials. Another significant cost blocking recycling today is the cost of transporting secondary materials for long distances. The fabricator or converter who is isolated from the reprocessor cannot justify these transportation costs and, therefore, his scrap becomes NP. The market price for scrap also has to be sufficient to justify the costs of storage and baling of scrap.

Another important impediment is the political one. As discussed in Part IV, the government often sets specifications requiring the use of virgin material, although in many instances secondary material has adequate performance characteristics. To give another interesting example, we have noted that the U.S. State Department in their AID Program removed secondary plastics from their approved list during the early part of 1970. Thus, foreign manufacturers today are unable to receive favorable financing from the U.S. on purchase of these secondary materials; and a substantial market for secondary plastics has disappeared.

Another impediment is the psychological one. As many of us know, consumers favor ''virgin'' materials. Virgin wool on the label sells sweaters; ''reprocessed'' wool does not. This is a common impediment whether the product is a plastic or a textile. Furthermore, up to this point in time, most fabricators have not broadcast that many of the plastic products they sell contain secondary material.

Finally, and certainly not last, are the technical impediments. Many of these have been mentioned throughout this report, particularly in Part I. As mentioned in Part I, plastics must be homogeneously one material and free of foreign contamination to be recycled easily and economically. The variability of the quality and supply of secondary plastics also has been a very severe restraint, for a fabricator needs assurance that both quality and supply will be maintained. Very often, fabricators have been sold on the use of secondary material; but once they receive a ''bad batch,'' secondary materials lose their attractiveness in spite of their low cost.

ALTERNATIVE METHODS OF PAYING SOCIAL COSTS

There are really only two alternatives to reduce the environmental damage caused by the disposal of NP: (1) to decrease the volume of NP in the disposal stream; (2) to change the composition of plastic materials in the disposal stream by increasing the proportion of easily disposable plastic products and decreasing the percentage of those that are more difficult to dispose of.

Differences in the disposability of spent plastic products is something that has been recognized only recently. It also signifies that there are differences between the private costs of some packaging and their true social costs. Consumers who purchase plastic products now pay only for the material, labor, advertising, and transportation involved in manufacturing and distributing a product. No part of the current price of the product offsets or reflects the cost of disposing of it, or at least removing it from the environment. To the extent that society must bear the cost of an inefficient disposal system, then, private costs of products are lower than their social costs. And any good that is underpriced will tend to be abused, misused, and misallocated. Packaging, according to this analysis, is underpriced--and abuse is rampant.

From first principles of welfare economics and allocative efficiency, it is desirable, then, to increase the private cost to at least approximate the ''true'' social cost. One way of doing so would be to have the consumer directly pay a disposer the cost incurred by disposing of his own output of nuisance plastic without causing substantial environmental damage. However, such an arrangement would be extremely cumbersome and difficult to enforce and would unduly increase the costs of disposal and, in turn, have a negative effect on the environment. In short, attempting to levy taxes directly on the consumer requires administering 200 million units as opposed to at most a few thousand industrial participants in the plastics cycle. Further, the information content of the tax (i.e., encouraging substitution of less ''damaging'' materials) is better received by the production decision maker, if he bears the initial burden of the taxes.

Alternatively, one can consider the concept of using a simple, across-the-board increase of the cost of all nonrecyclable plastic products. This would decrease environmental damage and also help defray the costs of disposal by making additional funds available to the disposers. The desired effects, however, would not be as pronounced as those that would accompany a differential taxing mechanism that would encourage the consumption of materials that could easily by disposed of or recycled. This could be carried out by imposing a lower tax or even a subsidy on the recyclable materials at the expense of those materials that are more difficult to dispose of. (See Solow's presentation before AAAS.[47]) Again, we should emphasize that an immediate implication of this analysis is that, although we are directly concerned with plastics in this study, we must raise the price of all substitutable materials unless we desire adverse selection with respect to plastics alone. Consistent with our goal of minimizing economic disruption, any strategy that involves this type of differential taxing mechanism should apply to all competitive materials; i.e., the tax must raise the price of all materials until they equal the sum of their social and private costs. This will have the effect of making the post-tax relative prices of all materials reflect their environmental damage.

To those concerned about the administration of any differential taxation scheme, we should point out that countries such as England, Sweden, and Holland rely heavily on just this type of taxation system to accomplish social goals within their economy. For example, the English system of purchase taxes, which puts a greater sales tax on luxury items as compared to necessities, is a fine example of an attempt to condition demand by creating financial tax distortions. It is a relatively ''fine tuned'' tax. We believe that the new goals of environmental protection require using similar techniques.

Regulation vs. Taxation

In a non-planned ''mixed'' capitalistic enterprise system[48] such as ours, there are basically only two ways to control or condition production and consumption: (1) regulation; (2) economic incentives or selected taxation. The essence of our system is consumer sovereignty, and the belief that resource allocation (production and consumption decisions) can best be guided by a price mechanism. Of course, for a resource allocation to be efficient (that is, produce the correct decisions), prices of services in the marketplace must reflect their true social cost. To use enforcement by legislation to promote recycling of a number of selected plastic products is inconsistent with this philosophy of a free-market economy. Controls should be used only when the consequences of certain acts are outrightly prohibitive (consumption of poison, for example), or when administrative impracticality renders taxation unfeasible. We believe that under a scheme of appropriate economic incentives, a balance can be achieved between the objectives of (1) minimizing environmental damage; (2) minimizing the cost of recycling and disposal; (3) minimizing economic disruption. Accordingly, the tactics recommended below are built primarily on economic incentives and disincentives rather than regulations.

Strategies That Require Legislation vs Those That Do Not

Schemes for promoting recycling of plastics that involve taxation, incentive payments, and regulation require legislative action, while schemes that involve education and changes in most aspects of government purchasing policy can be effected without requiring Congressional approval. Thus, these latter programs probably can be initiated sooner than the former. However, despite this barrier, schemes that require legislation may be required to reverse the present trend that promotes the use of virgin rather than recycled materials.

STRATEGIES THAT REQUIRE LEGISLATION

As this study has clearly indicated, the major impediment to recycling plastics today is the economic one. Therefore, promoting recycling necessarily involves economic incentives and, in particular, a scheme of selective taxation and incentive payments. We will discuss the following tactics to promote recycling: (1) a tax on virgin materials to widen the price gap between virgin and secondary materials; (2) an incentive payment to promote the use of secondary material; (3) a tax on all non-recycled products reflecting the true social costs of their disposal; this will be applied to all plastic products that are not easily recyclable; (4) a rebatable tax on all products that are recyclable; the bounty would be awarded to anyone returning the spent product to a collection point. These schemes, while primarily intended to influence production-consumption choices within a free-market environment and are directed at the economic impediment, will also yield resources. In fact, as will be shown, the rebatable tax may be self financing.

From an economist's viewpoint, the ultimate justification for a tax on non-recycled plastics is (1) to raise the costs of goods to reflect the true social costs, (2) to insure that the proper selection is made consistent with the objective of minimizing environmental damage. The justification is not in the use to which these revenues will be put, for even if society decided to use the revenues raised by taxing materials to merely reduce government deficit, the justification for the existence and level of a tax on plastics, for example, is unaffected. Likewise, society may well, and legitimately, decide to spend more revenue in environmental policing than is raised by taxing environment degraders.

Therefore, we recommend that revenues generated by any taxing schemes be considered as part of the Federal Government's general tax revenues. In general, we do not favor the trust-fund theory of taxation and revenue use. While this approach may be beneficial in the short run; in the long run it might invite the sub-optimization of public funds. While the government may wish to use these new revenues to solve the environmental problems today, they may wish to use these same funds for another purpose tomorrow. For example, the present Highway Trust Fund has caused just these difficulties. Today some government officials would like to use these funds for public transportation systems. Unfortunately, when the fund was set up, restrictions were incorporated preventing just this type of expenditure. Generally, trust funds are not satisfactory because they ‘‘lock-up’’ funds over an extended time.

Tax on Virgin Materials

A tax on virgin resins would directly affect the gap between the prices of virgin and secondary resins and thereby increase the demand for secondary resins. In the plastics cycle this tax is directed at the resin producer. Presumably, it would be passed on to the fabricators and to the other segments of the plastics cycle and ultimately to the consumer.

Mechanism. We recommend that the tax on virgin resins should be collected by the monomer producer who, in turn, would collect it from the resin producer by stating it as a separate item on the resin producer's invoices. Alternatively, the resin producer could list the tax as a separate item on his income tax. Though these monomers are usually used to make a number of products other than plastics, the government could easily audit the consumption of monomer for resin production either by requiring that the resin producer use special-metered pumps or by auditing the individual resin producer's production, based on the statistics that are made available each year. Thus, effective compliance with this type of taxation scheme would be expected, and administrative costs would be minimal.

This tax would be levied across the board on all resins on a pound basis using a density correction factor. Thus, materials of different densities would be taxed essentially on a volume basis, and the heavier PVC resin would bear a tax equal to polyethylene. There would be no reason to tax the resin types preferentially, because this is better "built into" other taxes. However, we caution that this tax cannot be levied on plastics alone. The tax policy on virgin materials should not be discriminatory against one material unless it can be demonstrated that the one material, in contrast to others, is severely damaging to the environment.

Primary Impact. This tactic can increase the demand for secondary resins because fabricators will now have a greater economic incentive to use them; but alone this tactic will not be very effective, because it will not assure an adequate supply of quality secondary material. Reprocessing costs would not be reduced and the raw material, namely scrap plastics, if anything would become more costly, if this tactic is used alone (see discussion below). Therefore, only a small portion of the NP will be converted to secondary resin. Marginal NP from the industrial sector will remain untouched. We estimate that perhaps 20 percent of the industrial NP or about 200 million pounds would be converted to secondary resin if only this tactic were applied. If a tax of one cent per pound were levied, which is a reasonable charge, the tax on virgin resins would yield an annual revenue of about 200 million dollars.

If consumer scrap were made available by some collection scheme, this tax on virgin material would promote its conversion to secondary resin; because this scrap plastic, in contrast to that from industry, could be made available at a relatively low price. As much as 1.5 billion pounds of this scrap are potentially available, if a collection and separation system is developed.

Secondary Impact. This tax would make scrap plastic more valuable to the resin producer and fabricator and thus tend to make them more efficient. The net tendency of this action would be to reduce the volume of NP produced. But any increase in the cost of industrial scrap plastic to the reprocessor as a result of this tax would negate the desired impact on the demand for secondary resins.

Another undesirable effect of this type of tax would be to reduce the demand for U.S. goods in the international market, because the price of these goods would be inflated. Conversely, the demand for foreign goods would increase in the U.S., and imports would be encouraged. Thus, this action would adversely affect our balance of trade. And, because this tactic must be applied to all materials, this effect could be very pervasive and tend to reduce our gross national product and thereby increase unemployment.

A counter balancing effect could be achieved, if consumer scrap plastic were readily available. Products made from this material would perhaps be cheaper than those manufactured from virgin resins, and, therefore, these products would be able to compete with those imported into this country.

Related Tactics. As noted above, this tactic requires others that will increase the availability of scrap plastic and secondary resin. Alone, the tax on virgin materials will not be very effective in promoting recycling, and the potential costs of this tactic in reducing our international sales are probably higher than the benefits.

Special Requirements of the Program. The administrative costs of this program are low; nevertheless, this program would require an agency that would be responsible for setting the level of taxation. Because we believe that the tax on virgin materials is primarily an auxiliary tactic, the level of taxation would have to be adjusted periodically. Initially, the tax would be set at a low level and then raised as needed to accomplish the desired effect of promoting recycling.

Incentive Payment To Promote Recycling

Just as the tax on virgin materials would widen the gap between the prices of virgin (particularly offgrade) and secondary resins, this tactic would be directed toward rewarding the user of secondary resins by further reducing his costs for secondary material. The primary objective of this tactic, then, is to increase the demand for secondary resin.

Mechanism. This tactic, in contrast to the tax on virgin materials, can be used to affect recycling in any one material category without employing it across the board in all material categories, although we would recommend that all material categories should be considered. Generally, this tactic will not place any one material at a gross advantage to another. This award can be made to at least three different segments of the plastics cycle (Figure 26): the fabricator, the reprocessor, and the consumer segments. Each location has its advantages and disadvantages.

One view is to offer the incentive payment to the fabricator who uses secondary resin. With this approach the fabricator could report his purchases of secondary resin on his income tax form and request an award of one to two cents for each pound of secondary resin purchased. Most fabricators use a certain percentage of their scrap as indicated in Part I, but the award would be made only for that purchased from a reprocessor or another fabricator as indicated by a sales invoice. However, this system would be complicated, because off-grade virgin resin is often sold as secondary resin, and thus this tactic would indirectly award the virgin resin producer. Therefore, a certification system would be required to insure that the incentive payment was made for the use of bona fide secondary material based on scrap plastic as the raw material.

Another alternative is to award the incentive payment to the reprocessor who purchases scrap and converts it into a secondary resin. The reprocessor could list his purchases of scrap plastic or his sale of secondary resin on his income tax form and request the incentive payment from the Federal Government. This approach, too, has its difficulties. First, the same problem of the off-grade resins exists, for the reprocessor often acts as a broker for this material; and second, if the award is made based on scrap purchase, the reprocessor may elect to receive the award and then dump the scrap into the solid waste stream rather than reprocess it. If the award is made based on the sale of secondary material, again the reprocessor may elect to ''sell'' it to someone gratis, who would then dispose of it improperly.

A third alternative would be to offer the award to the scrap generator. As indicated in Part III, most segments of the plastic cycle generate scrap, but the most significant segments are the resin producer, fabricator, converter and consumer. This approach has some of the disadvantages of the other two approaches, but it has some important advantages. By awarding the scrap generator, this tactic can both increase the supply of secondary material and at the same time increase demand. This may appear incongruous, but if the award is made, and the free market mechanism is then allowed to operate, the supply of less expensive secondary material will increase and the attractiveness of the secondary material as a substitute material will also increase. This tactic may motivate the scrap generator to segregate, store, and transport much of the scrap plastic that he now considers marginal to a reprocessing facility. This is the potentially valuable NP that is entering the solid waste stream today. Conceptually, both industrial and consumer scrap could be made available. Because of these advantages, we recommend this third approach.

One of the mechanisms for rewarding these incentive payments would be to have the scrap generator show by his invoices that SP was sold to a reprocessor or an outside fabricator. The scrap generator could then make a request to the Federal Government for this incentive payment, for example 1 to 2 cents per pound of SP, by listing the item on his Federal Income Tax form.

The sale of scrap plastic by the resin producers would be limited to a percent of production to avoid awarding them as incentive payment for producing virgin off-grade resins. Before devising this system of payments, standards would have to be determined by examining the resin producers' production records to see what portion of their production typically ends up as virgin off-grade resin.

To avoid the problem of having the fabricator receive an incentive payment for his own scrap, which he normally uses in manufacturing, we recommend that the payments only could be awarded to the scrap plastic generator, if the SP were sold to an outside organization. As indicated in the earlier section of this report, recycling within the industry is very expensive, and the intention of this award mechanism is to promote the recycling of plastics which today normally end up as NP. Thus, if a fabricator uses his own scrap, the size of the award would have to be such that it would be undesirable and inefficient for him to ship this scrap to a reprocessor just to collect the award. This factor must be considered in determining the actual amount of the incentive payment that would be offered.

Primary Impact. As noted above, the third mechanism will effect both the supply and demand for secondary material.

Effect on Supply. In Part III of the plastics cycle, we noted that there are two sources of NP: that from industry and that from the consumer. Although the industrial NP amounts to about 1 billion pounds per year today, perhaps no more than 75 percent of this is actually usable for recycling because some is grossly contaminated. Thus, as an optimistic estimate, approximately 750 million pounds of NP (potentially SP) would be available from the resin producer, fabricator, and converter. Recall that this will be supplemented by an additional 1 billion pounds of scrap plastic that is being presently reprocessed each year. In accordance with the objectives of this study, we especially desire incentives that promote the recycling of industrial scrap plastic that is relatively clean and is generated in isolated locations, i.e., not in the vicinity of a reprocessor. We believe that this system of awards should do so.

Disposal of this NP that could be converted to SP is costing industry about four to seven million dollars a year today, and most of the expense is passed on to the consumer. Most industrial establishments use private scavengers who have their own disposal sites. Thus, the industrial scrap generator has an additional incentive to provide the scrap to the reprocessor, for not only would he receive an incentive payment, but he would eliminate some of his disposal costs.

This incentive system may also motivate the formation of centers for the separation and collection of consumer NP, especially that from large institutional and commercial consumers. These centers also could receive this incentive payment, according to the preferred mechanism. Although the amount of consumer NP is much greater, most would be difficult to retrieve based on current technology, either because the NP is part of a composite or a multiplastic system, or it is not economically collectible. Potentially, then, as noted earlier, only NP derived from spent packaging can be recycled. This amounts to 60 percent of the total NP. However, because of the need for collectibility and for monoplastic materials, at this time no more than 1.5 billion pounds of consumer NP are available for recycling. This is equivalent to all monoplastic rigid type packaging.

Realistically, however, the most collectible items are plastic bottles, at least during the early stages of any consumer recycling program. Over 600 million pounds of plastics were used to make bottles in 1970, and this market is expected to increase to 1600 million pounds by 1980 (exclusive of the new acrylonitrile plastics on the horizon). Of the ‘‘big-five’’ plastics used to fabricate bottles, over 80 percent is HDPE; and in 1970 over 500 million pounds were used (Table 51).

A high density polyethylene is used to package such major products as milk, bleach, detergents, and other liquid laundry detergents (Table 52). Packaging for these products accounted for 400 million of the 500 million pounds of HDPE used in 1970. We have estimated a relatively deep penetration of the milk market by the all-plastic containers. These estimates were made assuming no major impact due to the present outcry of the ‘‘environmentalists’’ against plastics. Other rigid containers made of HDPE that are potentially recyclable include shampoo tubes, margarine and delicatessen tubs, ice cream containers, baby powder containers, motor oil cans, and containers for industrial chemicals (1 gallon size).

Fortunately, only two major grades of HDPE are used for these bottles. Thus, the successful collection of bottles such as those used for milk, bleach, detergents, and other laundry liquids could go hand-in-hand with separation. Although effective collection of these spent containers from the consumer would remove only 7 to 8 weight percent of the total NP, it is the volume occupied by this potentially recyclable NP that is more significant. The spent plastic bottles, if uncrushed, might represent as much as 30 percent of the plastic wastes on a volume basis. Thus, effective collection of this NP and conversion to SP can remove a large portion of the most environmentally damaging NP. As a maximum, this consumer SP would amount to no more than 750 million pounds. Today, disposal of this NP costs society at least 7 million dollars per year (including collection).

According to the above analysis, then, a realistic estimate for 1970 of the total potential volume of recyclable NP from both consumer and industry sectors is approximately 1.5 billion pounds; equal volumes from the industrial and consumer sectors. This could increase to about 4 billion pounds by 1980 and, if the consumer recycling programs are successful, a much larger proportion of packaging wastes may be recycled.

TABLE 51

PLASTIC BOTTLES IN THE DISPOSAL AREA*

Type of plastic	1970 Million lb.	1970 wt. %	1975 Million lb.	1975 wt. %	1980 Million lb.	1980 wt. %
HDPE	524	84.0	920	87.0	1409	87.9
LDPE	32	5.1	35	3.2	40	2.5
Polypropylene	10	1.6	12	1.1	15	0.9
PVC	58	9.3	92	8.7	140	8.7
TOTAL	624		1059		1604	

* Source: A. D. Little

TABLE 52

HDPE BOTTLES*

Type of product	1970 mm/lb.	1975 mm/lb.	1980 mm/lb.
Milk	140	450	800
Laundry bleach	100	105	115
Liquid detergents	94	98	100
Other laundry liquids	79	85	90
Toiletries and cosmetics	80	140	240
Cleansers	8	10	15
Medicinal	17	20	25
Edible oil	6	12	24
TOTAL	524	920	1409

* Source: A.D. Little

Effect on Demand. Under this incentive award system to the scrap generator, we believe that fabricators and compounders would be motivated to use more secondary resin, because an assured supply of the secondary resin would become available at relatively low prices. Some of the fabricators interviewed during this study indicated that if the price differential between the secondary resin and the virgin material (in the case of polyolefins) were as little as 2 cents per pound, they certainly would take a second look at using secondary materials.

With the increase in the supply of scrap plastic both from the consumer and industry, assuming a free market economy, the price of scrap should decrease. Scrap plastic, as indicated previously, is the raw material used to make secondary resins. If the price of the raw material goes down, the price of the secondary resin also could go down; but it need not do so, for the secondary resin is a substitute good, that is, it derives its price from its value as a substitute for the virgin resin in some applications. Thus, in effect, virgin-resin producers today control the entire resin-price structure, if anyone can be said to be controlling resin prices.

Considering the selling price of secondary resins, one has to realize there are lower limits, unless the government steps in and provides a direct incentive to the reprocessor. However, we do not believe that this will be necessary; the recommended scheme should provide a sufficient incentive for the reprocessor. The cost of secondary resins is largely determined by three factors: (1) the cost of raw materials, i.e., the scrap plastic, including transportation; (2) the cost of reprocessing; (3) a reasonable return for the reprocessor. It is important to note that even if raw materials were available at no cost, the other two factors today often approximate 3 to 5 cents per pound. This, then, can be viewed as a lower limit for the selling price of any secondary resin under the present conditions.

However, if the price of secondary resin is lowered, there may be no increase in its demand. As indicated in previous sections of this report, a number of barriers exist today that restrict the application of secondary resins; for example, both government and industry use numerous specifications that actually ban the use of reprocessed material. In other words, a price insensitive ceiling on the demand for secondary resins may exist. In this case, the only way to increase the demand for secondary resin is to expand their markets. Some of the methods for doing so are outlined below. However, even without a great deal of user education, we believe that if more secondary resin were to become available at a price considerably lower than the competitive virgin material, new markets will automatically arise. As one of the fabricators mentioned, ''if you can guarantee a sufficiently large volume of secondary resin with an assured quality, we will find applications.''

In all likelihood, secondary resins will replace the virgin materials in those areas of applications that do not require resins with very narrow specifications. But hopefully, the secondary resins will be able to enter into brand-new markets where they will not be competing with plastics but with materials such as wood, cement, etc.

Cost vs Benefits. If the incentive award were one cent per pound, the costs to the Federal Government for the payments to the industrial sector (this includes the one billion pounds of SP that is currently recycled by the reprocessor) would be 17.5 million dollars. If the payments to the consumer sector are included, the total cost would be 25 million dollars. Considering the total cost of this program at the one cent per pound level, and the benefits to society calculated only on the basis of disposal costs, which is a very narrow view, the net cost of this program for plastics would be 10 million dollars per year, based on 1970 production statistics.

In actuality, the net cost of this program will be somewhat less, because the displacement of primary or virgin materials by secondary ones will reduce the costs of the present government programs that effectively subsidize the producers of virgin material. The producers of virgin materials, and plastics as no exception, have a number of tax advantages. Most noteworthy is the system of depletion allowances that was developed during the period when our country was trying to promote the development of our natural resources. Thus, in effect, the incentive payment will shift a portion of the tax benefits now received from the utilization of virgin materials to the utilization of recycled materials.

Secondary Impact. The use of the incentive payment described above can affect the secondary and primary plastics industries very directly, and this tactic may promote a deeper penetration by plastics into the marketplace enjoyed by other materials.

If the recommended strategy is successful and more scrap plastic becomes available, the reprocessing segment may have to double its present production. Therefore, we would expect some economies due to this higher production volume, and also we would expect significant improvements in technology that would tend to make the reprocessing operation more efficient. Because of this expected growth, it will be important that this reprocessing function be carried out primarily by independent operators in a highly competitive framework. Without sufficient competition, the lowering of the price of scrap plastic by this tactic may contribute more to raising the profits of the reprocessors than lowering the price of secondary resin. In our study we noted that a few resin producers are also considering reprocessing to improve their profits. We believe that if the reprocessing function were performed exclusively by the resin producers, a conflict of interest situation and an undesirable concentration of economic power would result, which could easily jeopardize the effectiveness of any overall program.

On the other hand, some combination of the reprocessing and fabrication activities may be desirable, if the reprocessors under these new improved economic conditions are still unable to generate sufficient profits and are unsuccessful in developing the required new markets for the new resin. Thus, the new reprocessor/fabricator would purchase scrap plastic at very low prices, reprocess it, and then convert it into a relatively high value fabricated product, such as plastic pipe. In this way the reprocessor would improve his profit margin, and he would clearly demonstrate to his fabricator customers that the secondary resins indeed can be used successfully.

The primary plastics producers could lose some of their markets, if this tactic is successful in promoting the use of secondary resin, namely, those markets that are served today by relatively inexpensive lower quality material. With the influx of the recycled resins, the resin producer could perhaps concentrate on the sale of the higher quality material and thereby increase his efficiency, because he would not have to sell a wide range of resin grades. Hopefully, he would then also increase his profit margin. Thus, perhaps the growth of the resin producers' sales during the coming year would be slowed, but he would improve his earnings.

Plastics are currently displacing many of the traditional materials, as discussed earlier, especially those used in construction. Secondary resin, and scrap plastic itself, is very suitable when incorporated in such items of construction as panels, pipe, conduit, and concrete (see Part IV). Therefore, if this tactic is effective, scrap plastic and secondary resin, rather than primary resin, will be used increasingly as these new markets open up.

The net effect of this tactic on those industries using clay, concrete, paper, and wood in construction items will be to reduce the size of their market at an increasingly rapid rate. This change is already occurring, but the availability of inexpensive secondary resin will speed the change. In recent years, many of the companies who produce items from the traditional materials have become fabricators of plastic parts and, therefore, this tactic will further promote this transformation. Note, that from the solid waste point of view, this transformation is a good one, because it effectively removes NP and ''buries'' it in items having a long service life.

Related Tactics. This tactic could be used alone to promote recycling, for it does not necessarily require auxiliary tactics. However, because an incentive payment requires a net payout by the government, a desirable auxiliary tactic would be one that generates funds such as the tax on virgin materials or the tax on non-recyclables described below. These funds, then could be used to provide the awards to the scrap generator.

Special Requirements of This Program. This program will be somewhat more difficult to administer than the tax on virgin materials. As mentioned above, standards will have to be developed to prevent the primary resin producer from collecting an incentive payment for his ''off-grade'' material. A government agency will be needed to set incentive payments for different materials and to change these payments as needed to promote recycling.

Tax on Non-Recycled Products

The primary objective of this tactic is to promote the demand for recyclable material and, therefore, the supply of consumer scrap plastic, assuming that an effective collection and separation system exists. If the product cannot be made available in an easily recyclable form, then the secondary objective of this tactic is to reduce its disposal and social costs and, ideally, this tax should be computed to reflect these.

Mechanism. This tax would have to be levied on products made from all materials to avoid adverse selection, as discussed previously. A ''finely tuned'' tax would reflect at least four different properties that measure the disposability of a spent product: (1) service life; (2) chemical composition; (3) volume occupied by the spent product in the disposal area; (4) compressibility, which reflects the ease with which the volume of the spent product is reduced by the various intermediate treatment processes and/or the final disposal process.

The service life of a product is a dominant factor in considering the disposability of any product. Items such as packaging that have a short service life dominate the disposal area, as noted in earlier sections of this report. Therefore, considering disposability, a product having a short service life is less desirable than one having a long service life. A practical approach to computing a tax based on this property would be to have a number of service life categories; for example, items having a service life of 0 to 1 year would have one tax rate; those up to 5 years another; those up to 10 still another, etc. The longer the service life, the lower the tax.

The chemical nature of the material used in a product is important, if the spent product is incinerated. For example, products containing PVC that would require more costly incinerators and higher maintenance costs would bear a higher tax than products containing polyethylene. The chemistry of the material also may have an effect on its disposal characteristics in a land-fill operation, as discussed in Part III; although, at the present time this really is debatable, for in many instances a non-biodegradable material is desirable.

Throughout this study we have mentioned the problems and costs of disposing of spent products having a low bulk density. Accordingly, a voluminous rigid container that is not recyclable should bear a higher tax than a container such as a polyethylene sack that usually lies flat after it has been emptied. This bulk density property is important both in intermediate and final disposal, as well as collection. Therefore, it also is a dominating property. In using this property to compute a tax, the simpliest approach would be to consider the volume of the spent container in the intermediate disposal area. The compressibility property would then ''correct'' for any volume reduction in subsequent disposal operations.

In considering the compressibility of a spent product, we must also consider its resiliency or ''spring back.'' Some containers, for example, plastic-coated milk cartons, are quite compressible and are usually compressed when they are first discarded in the garbage can. Furthermore, these containers can undergo additional volume reduction during the later stages of collection and in ultimate disposal. On the other hand, a rigid polyethylene container, if it is not granulated, typically retains its shape in the garbage can and is compressed with great difficulty, even in a land-fill operation. Accordingly, the all-polyethylene container would bear a higher tax than the plastic-coated milk carton, based on this one property.

This listing of different properties of materials related to disposability is not meant to be inclusive and a more detailed study may be required. Darney,[49] in his excellent report dealing with packaging in solid wastes, listed a number of other characteristics. However, in developing this system of taxing, one need not go into an extremely detailed analysis of every characteristic of the material with respect to its disposability. We believe that those mentioned above are the most significant properties. Again, considering a practical approach, we would recommend that all of these property ratings should be categorized to include groups or classes of products. If need be, only the two characteristics--service life and volume--could be used to compute the tax.

Darnay weighted the different disposability characteristics according to their importance in each particular disposal process. However, for simplicity, we can consider the following processes: collection, land fill, and incineration. Collection would be weighted most heavily, because it is the major cost of disposal today. Because this tax reflects the cost of disposal and the social costs of environmental damage, the development of weighting factors for each of these processes will have to be considered very carefully.

We developed the following equation for computing a materials tax.

$$\text{Total Tax } T = S\,[Ci + V(1+c) + P(1+c)]$$

Where S = the tax for the service life property
C = the tax for the chemistry of the product
V = the tax for the volume or bulk density property
P = the tax for the compressibility property
i = the weight factor for incineration
l = the weight factor for the land-fill process
c = the weight factor for collection

Considering that a product with a long service life would have little effect on the environment, we used this property as a multiplier because it has an overriding effect. For example, products with a service life of, say, 25 years could have a tax S = 0 and, therefore, the materials tax ‘‘T’’ would be equal to zero. C is multiplied by the weighting factor i, because C reflects a property that is primarily significant in incineration, whereas the other properties reflected by V and P are important in collection and in final land-fill disposal.

In this study we have not attempted to assign numbers and actual weighting factors for these properties or processes; this goes beyond the scope of the present study. The intention is primarily to illustrate methodology. Furthermore, in many instances, experimental work will be required to rate various products such as packaging materials, and the weighting factors used for the process will be expected to change with time. However, we believe that a system of rating packaging materials or any other materials is possible and should be done. Again, it need not include every possible product, but it can be applied to groups; and a simple version would include only the service life and volume properties without the various weight factors.

This materials tax would be computed on a weight basis but with a density correction factor to correct for materials of different density, as described for the tax on virgin materials. Thus, the tax for a glass product (glass is 2.6 times as heavy as polyethylene) would be computed on a pound basis, but then divided by a factor that would equalize the tax on materials of different density. The tax based only on weight would be unfair, because heavier materials such as metals would bear a disproportionately high tax that could not be justified based on its effect on the environment during disposal. Volume is the significant factor, as mentioned earlier, and the tax, theoretically, could be computed on a volume basis alone; but this would be impractical, because often the volume of an irregular sized product would be difficult to measure. However, computing the tax on a weight basis using the density correction factor has the advantage that it can take into account the effect of disposing of products with different wall thicknesses. Thus, if we compared two polyethylene containers of equal volume, the container having the thicker wall would bear the higher tax, which is consistent with the objective of this study.

Plastic films and coatings are a special case in the disposal area. For example, the disposal of plastic film whether 10 mils or 1 mil thick is equally costly. Using the formula above would mean that the thicker film would bear the higher cost. In order to compensate for this effect, on a pound basis, the material tax could be reduced for the thicker film. Thus, the area of the film becomes more significant. But, this problem of film will require more study, because there are important trade-offs to consider. For example, one could also argue that the thicker film uses more material and, therefore, consistent with the objectives of this study, the thicker films should bear the higher tax. As in the other instances, the film would be classified into a number of ranges of thickness, and a different tax rate per pound would apply to each range.

The materials tax would probably add no more than a few cents to the cost of a typical rigid plastic package. No matter where this tax would be levied in the plastics cycle, all or most of it would probably be passed on to the consumer. Considering that today's consumer is unaware of the costs involved in packaging the product he purchases, he probably would be unaware of the small tax. On the other hand, the packager is keenly aware of his packaging costs, and it is he who should get the message, namely, that packages differ in their disposability characteristics.

A major concern with adopting this type of tax would be that of ''double-taxation.'' The problem is that the consumer, who pays the disposal fee for the product at the store, would also have to pay for the disposal of his refuse either to the trash collector directly or as a tax to the municipality. This argument would be valid if the tax were levied only on one product such as packaging; however, the scheme described above applies to all materials. Thus, there would be little need to pay an additional tax for general refuse collection. Conceivably, items such as demolition and agricultural wastes, which are not covered by the materials tax, would have to be handled differently. If they could not be ''carried along'' with the funds generated by this taxation scheme, then a separate collection fee would be needed.

Location of Tax. All of the key disposal properties described above have been imparted to the product by the time it reaches the manufacturer/packager segment. The chemistry of the product usually has been established in the very beginning of the plastics cycle by the resin producer. To tax him in a way to reflect the effect of this chemistry factor, however, would be difficult, because each resin is used to make a variety of products and some have different service lives, as pointed out in earlier sections. Though PVC, for example, is considered deleterious, its effect is most apparent with the products having a short service life such as packaging. On the other hand, PVC-coated fabrics with their relatively long-service-life properties are a very small component of solid waste and thus less damaging to the environment. Tax levied at the fabricator level also could run into difficulty. For example, the fabricator who makes plastic sheet also makes it for a variety of products with different service lives. In this instance, it is the converter, then, who determines the service life property. Accordingly, we recommend that this tax be levied at the manufacturer/packager segment. It would be collected by the Federal Government and would appear as a separate item on the invoices for the purchases of material from the fabricator/converter segment.

Primary Impact. If an effective collection and separation system exists for spent plastic products, then this tactic can promote recycling, because the consumer would select the less expensive recyclable product that would not bear this tax. As a result, the packager/manufacturer would also get the right message. However, as indicated earlier, the recyclable product such as the rigid polyethylene container can be viewed as relatively damaging to the environment (high disposal costs) because of its low bulk density. Therefore, this tactic will require an auxiliary tactic such as the rebatable tax described below to insure that potentially recyclable plastic products are indeed collected and separated, otherwise all plastic product whether potentially recyclable or not should bear a tax.

Assuming that the recycling of spent plastic products from the consumer is a viable operation, this tactic will tend to further increase the production of rigid monoplastic containers, because these are the items that are most easily collected. As mentioned in the last section, even without this tactic we expect an increasing penetration of plastics in the container market. The consumer apparently prefers the rigid plastic container if he has a choice. For example, in a recent panel test conducted by Mary D. Zehner at Michigan State University, Detroit consumers were given an opportunity to rate three types of milk packages, namely the rigid plastic milk container, the paperboard carton, and the flexible plastic pouch on the basis of handling and storage characteristics. No reference was made of costs. According to the 112 panelists, the rigid plastic container was preferred.

This tax on materials can generate substantial revenues that can be used in other programs designed to reduce solid wastes. Presumably the products that have a long service life, such as items of construction, transportation, etc., will not bear this tax. These products represent about 70 percent of all plastics consumed. The remaining products (packaging, toys, housewares, etc) amounted to 5.7 billion pounds of plastic in 1970 and these would be taxed at different rates. Assuming that the average tax amounted to two cents per pound, about 100 million dollars would be generated by this type of tax.

Secondary Impact. This tactic should reduce the volume of nuisance plastic in the disposal area, particularly the more troublesome variety. Recall that this tax will be levied on all materials, therefore, the volume of these, too, will be reduced in a similar manner.

Plastic packaging that is not recycled will tend to be produced in flexible rather than rigid form, because flexible packaging material will bear a lower tax than rigid. Plastic pouching, therefore, will be promoted because it uses a minimum weight of material and occupies little space in the intermediate and final disposal areas.

Thus, the impact of this tactic will promote either the rigid monoplastic container or the plastic pouch, depending upon the success of any recycling program. If recycling from the consumer segment is negligible, the plastic pouch will take over those packaging areas that are ripe for a change.

Related Tactics. Throughout this discussion we have mentioned that this tactic is really an auxiliary one, for it depends on some other tactic to insure that plastics are recycled (see The Rebatable Tax).

Special Requirements of This Program. A thorough analysis of the disposability characteristics of spent products will be required to establish the various taxation levels suggested by the equation developed above. The tax will have to be equitable to accomplish its goals and prevent undesirable substitutions.

This tactic will require an administering agency to set the levels of taxation initially and review them periodically. Because this program is somewhat more complex than those mentioned above, administration expenses may be an important factor when one compares the costs vs the benefits of this tactic. The administering agency will have to monitor this program continuously to insure that the complimentary program that was designed to promote recycling is indeed effective, otherwise this program will fail.

Rebatable Tax

The objective of this tax is to directly promote recycling by providing a supply of scrap plastic primarily from the consumer. This tax is essentially a tax on plastic packaging materials, for these are the most easily recycled. The effectiveness of this tax obviously depends on the availability of a collection and separation system.

Mechanism. In this scheme the consumer would receive an award payment to pay for his costs of sorting, storing and, if necessary, transporting spent containers to collection centers. These containers would bear a rebatable tax. According to the recommended scheme, interception via a collection center is only one technique. Collection from the home is not ruled out. Generally, the concept of this tax is to reward the householders or other institutional consumers to the degree that they contribute to the disposal of the spent package. Presumably, the consumer would receive a higher rebate if he brought it to a collection center than if it were collected from his home or place of business. This tactic could not be used for plastic items alone; it would have to apply to all packaging materials to avoid undesirable substitution effects.

An inducement wage for the consumer, or the amount of tax rebated, need not be a function of the market value of the returned containers. More properly, the rebate should depend on the cost to society of neglecting the collection and return of the nuisance plastic. Thus, the tax on each spent container should equal the marginal social costs of not having it turned into a collection center. These should include the cost of collecting and sorting, or the real value of the container's marginal addition to environmental damage, whichever is less. If that cost is brought home to the consumer, then it ought to be up to him whether he chooses to pay it or not. If he chooses to pay it, and does not bring the spent containers in for recycling, then one can argue that he ought to be allowed to do just that; otherwise, a higher tax would unduly distort the allocation of resources toward recycling. Part of the reason for this, of course, is that returns from the unrefunded tax on the unrecycled containers can be used to collect those containers, but the general reason is stronger. It lies in the proposition that consumer sovereignty ought properly to be respected. Provided that the full resource costs of a decision are brought home to consumers, free-market economy should result in an efficient allocation of resources.

One can consider the following equation in developing a rebatable tax:

Old Tax Revenues + New Tax Revenues + Resale Price of SP =
Inducement to Consumer + Collection and Granulating Costs

The left-hand side of this equation can be viewed as the ‘‘kitty’’ of resources which society might use to defer costs that are measured on the right-hand side. Old tax revenues are those that reflect the disposal costs obviated by the new recycling system. (In some cities, disposal costs amount to more than 1 cent per pound.) The new tax revenues are those received from the taxing of recyclable packaging materials; and the resale price is the selling price for the scrap plastic derived from the spent container.

This equation does not have to hold exactly. There is nothing wrong if the right-hand side is greater than the left-hand side, as long as society has chosen to spend more on ridding itself of NP than it can obtain directly from tax and resale revenues. Furthermore, as noted in the earlier discussion, the market price of scrap plastic in no way dominates or determines the economic viability of any recycling scheme, as long as society has decided that the costs of environmental damage caused by the normal disposal of these spent containers are greater than the difference of costs between the right and left sides of the above equation.

The rebatable tax would be levied according to the size of the container--the larger the container, the higher the tax; and it would be levied on all potentially recyclable containers. Often different types of rigid containers (plastic, glass, and metal) are used to package the same product, whether it is milk, water, a detergent, etc. If one of the containers for a given product such as milk is recyclable, an equivalent tax would then be levied on all rigid containers used to package this item. The amount of tax would only vary according to the size of the container (quart, pint, gallon, etc.) and not with the type of material. Thus, this measure would provide a powerful incentive for promoting the use of recyclable packaging.

Consider the packaging of milk. Presently, milk comes in the following containers--plastic-coated paperboard, all-plastic, and glass, and in some instances it is provided in a flexible polyethylene pouch, as described in an earlier section. The flexible container and the plastic-coated paperboard container would not be subject to a rebatable tax (they are not easily recycled at this time), but they would carry a material tax, as discussed in the previous section. At this time, however, only the all-plastic and glass containers are completely recyclable, therefore, only they would bear the rebatable tax. Thus, if no means are found to recycle the flexible pouches and both the pulp and plastic in the plastic-coated paperboard carton, these containers would undoubtedly be replaced by recyclable containers, if the former carried a low material tax. Of course, this depends on the relative costs of the recyclable and unrecyclable containers to the consumer. These costs could be adjusted by the two types of taxes (rebatable and material) so that the ‘‘right’’ decision is made to minimize environmental damage.

Location of the Tax. The rebatable tax would be imposed on the wholesaler/retailer segment of the plastic cycle, and collected by the packager, who would list the tax as a separate item on his sales invoice. The initial incidence or the location of the tax is important, and alternatives exist. The earliest point in the plastics cycle where such a tax could be imposed would be at the fabricator level, where the container is made. However, we believe that this tax should be collected as late in the cycle as possible. If the tax were imposed on the packager, he would have to pay the tax, for example, every time a container was mislabeled or damaged during filling. This would have little effect on promoting recycling, and it even could be considered a disincentive.

In this scheme, conceivably, the fabricator can label the container recyclable and, if required, a special code can be used to denote a particular plastic or even a particular grade. This is easily done by embossing the container.

On the other hand, a stamp or label showing that the rebatable tax has been paid can be affixed either by the packager or by the wholesaler. One scheme for labeling is to use a machine similar to the postal stamping machine. Thus, the packager would purchase a certain number of ''stamps'' or labels that would be affixed during the normal filling operation. For example, this system could be designed so that the employees of the collection center could count their inventory of spent plastic containers by punching the returned container through the labeled section to produce a labeled plug. These plugs could then be used as a basis for an auditing system, when the Federal Government reimburses the collection center.

Collection. The consensus of our strategy panel was that an adequate refund under this tax scheme would be between 10 and 25 cents per container, depending on its size. Comparable refunds would be made for containers whether they were made of glass, aluminum, etc., as long as they were recyclable. Interestinly, a recent survey[50] showed that over 80 percent of the consumers interviewed would be willing to separate some or all of their discarded packages. The interview included representatives of large and small cities, suburbs, and the rural area. Approximately 50 percent would be willing to deliver these containers to a central point; however, over 70 percent expected a payment of at least 50 cents per waste can. Furthermore, only 22 percent were willing to deliver gratis. For obvious reasons, those living in large cities were least willing to deliver their empty containers to a central point. As one respondent replied, ''How do you carry a garbage can on the subway?''.

These collection centers in some ways would be similar to the existing ones described in Part IV. However, they would collect all types of containers bearing the rebatable tax stamp. Furthermore, they would be placed at strategic locations throughout the large metropolitan areas, particularly near shopping centers. Many of the collection centers in the current glass and aluminum programs are located either near a manufacturing facility or a bottling plant; they are not usually located for the convenience of the householder. Because the householder does not like to make separate trips, he would rather bring his discarded containers to locations such as shopping centers that he frequents. Hopefully, these centers would be designed so that they themselves do not represent an environmental insult; oftentimes, the public has complained about the unsightliness of collection centers that have been put up in haste.

The collection centers needed for this program would be operated either by town, city, or county government; although private ownership is not ruled out. In this case, though, the operators of the centers would act as agents for the Federal Government. If at all possible, operation by a county office would be preferred because it is responsible for a region that can be handled conveniently from the point of view of solid waste management. Note also that these centers offer new job openings; some of these would be in the central-city areas where they could be filled by the readily available non-skilled labor pool.

We have little information on the costs of collection centers of this type, because none exist at this time. However, this information will be valuable in determining the economic viability of this approach and, therefore, we recommend that the Federal Government sponsor a demonstration program designed to determine the most efficient way and the cost of operating this type of facility or one where a separate collection of packaging materials is made from the home. Remember that this center or the home collection system will be collecting various materials, some of them, such as aluminum, command a relatively high market price. Thus, these items will help defray the costs of collecting other materials that have a relatively low value in today's market. Granulated polyethylene, for example, sells today at a price of $20 to $60 per ton, depending on its degree of contamination.

Because of the extremely low bulk density of empty plastic containers, it would be best that these collection centers granulate the plastic at these sites. A number of companies today make suitable granulators for this type of operation. Any further reprocessing probably would not be justified, because the volume of scrap plastic generated at a particular collection point would be relatively small. An alternate approach, similar to the one described in Part IV, would be to install granulators on the trucks that gather the scrap plastic from the collection centers or the home. Although collection centers may be viable for large population centers with a population greater than 500,000, these centers would be difficult to justify in rural areas, recognizing that each person generates on the average only 3 to 4 pounds per year of the desired recyclable plastic scrap.

The alternative approach of collecting from a retail outlet also was considered. However, not only are retailers very reluctant to collect returnables, as indicated in previous sections, but limiting collection to the retailer might mean that the consumer would have to deliver the spent packaging items to more than one retailer. This would be extremely inconvenient. Moreover, the collection center approach, we believe, is a better one because it allows for the consolidation of larger volumes of scrap plastic and other materials at one point.

Returnables. As mentioned previously, milk is available today in returnable plastic containers, and potentially other products can be packaged similarly. In our view, the existing system of returnable plastic containers bearing a deposit can continue side-by-side with the rebatable tax scheme. The returnable containers would also bear a rebatable tax, but the tax for a given size container would be less than that for a one-way container, and it would be less than the deposit that would be received if the consumer returned the bottle to the store or delivery man.

For example, a one-gallon returnable bottle could bear a 25-cent deposit that would include a 10 cent bounty under the rebatable tax scheme. Thus, the consumer would have an incentive to return this spent container through normal ''returnable-bottle'' channels rather than to a collection center. The dairy man, in turn, would still receive his normal 25-cent deposit, but he would have had to pay a 10 cent or less rebatable tax from this deposit fund. If the bottle made, for example, 100 trips, the rebatable tax paid on each trip would be no higher than 0.1 cent. Once the returnable bottle is considered ''spent'', the dairy could return it and obtain the 10 cent bounty from the collection center. If the returnable bottle is in good condition and is turned in at the collection center, the operator of the center also has the option of collecting the ''deposit'' from the dairy.

Administration of Funds. As indicated above, the rebatable tax will be used to motivate the consumer to return recyclable plastic containers to collection centers. The rebate they receive is to be covered by the tax revenues. If local governments are to be made responsible for the operation of collection centers, the Federal Government would reimburse them for the cost of operating the collection centers. Thus, the Federal Government would distribute the new tax revenues to the local governments. But, we believe that some local funds also should be used to cover operating costs; perhaps as much as 90 percent of the funds should be provided by the Federal Government and 10 percent by the local government.

Primary Impact. This tactic, if successful, could generate about 400 million pounds of scrap HDPE from the consumer per year based on 1970 consumption statistics, and perhaps as much as 1100 million pounds of scrap HDPE by 1980, which still represents only about 5 pounds per capita per year. These statistics assume that the consumer would be asked to return only the plastic bottles used for the major commodities, namely milk, bleach, and detergents. This approach has the advantage that it would generate a ''clean stream'' of one plastic material (HDPE) and, therefore, further separation of the plastic fraction of the solid waste stream would not be required. Control over which bottles would be returned would be very simply using this rebatable tax scheme. However, because this tactic would generate only a small amount of plastic material, it would be imperative, as indicated above, that the tactic be applied to all packaging materials, otherwise the costs of this approach could never justify the benefits achieved in reducing the volume of solid wastes and providing a supply of easily recyclable plastics.

The rebatable tax scheme is consistent with the objectives of this study because the decision maker in the plastics cycle, namely the packager, would purposely select recyclable containers to package his product. If he knows that the consumer will not have to pay an additional tax for the recyclable containers, but in fact may receive a bounty, the packager will be strongly motivated to make the ''right'' decision. Incidentally, the bounty could be greater than the amount of the rebatable tax levied on the container.

The fabricator of recyclable containers will be content with this strategy. However, if he now fabricates a container that is not recyclable, he will be strongly motivated to change his product line. Thus, within the plastics cycle each segment would be motivated to make the right decision that would result in increasing the supply of consumer scrap plastic.

This tax scheme can generate sufficient funds so that the collection system will not require a subsidy. But, until the costs of collection and separation are known, the relative costs vs. benefits will be unknown; and there is the risk that if the rebatable tax levied on a container is too high, the tax would be very regressive and a major portion of our population would select the non-recyclable container bearing a smaller tax, even though perhaps the ''net'' cost of the recyclable container to the consumer could be lower. Thus, the objective of this scheme could be thwarted.

Secondary Impact. Although the volume of scrap plastic generated by each consumer is small, potentially it does represent a major portion, about 50 percent, of the available NP (industrial and consumer) that can be converted to SP. The scrap generated by this scheme should be relatively clean, of high quality, and useful in a number of applications. This increase in supply will keep the price of scrap low and as explained, in an earlier section, will result in a low price for secondary resin, and therefore, an increase in its demand.

The effect of this tactic on the overall costs of collection and disposal of solid wastes will be minimal; because even if this approach is successful with all containers, it will remove only about 4 weight percent of the total urban wastes generated in this country. This estimate is based on results reported by Darnay,[45] where he calculated that 13 weight percent of the 350 million tons of urban wastes generated in 1966 in the U.S. were derived from packaging wastes. Even if one considers the huge volume of packaging wastes generated in New York City, which amounts to 40 weight percent of the 6 million tons of solid waste generated each year, excluding demolition wastes, rigid containers (metal, glass, and plastics) account for only about 12 weight percent.[51]

On the other hand, considering nuisance plastics alone, this scheme, if successful, would remove as much as 30 volume percent of the NP because uncrushed plastic bottles are voluminous, as mentioned previously.

Related Tactics. As mentioned throughout this section, this rebatable tax could not be levied alone; both the materials tax and the incentive-payments to promote recycling system are needed to effectively promote recycling. The rebatable and materials taxes are complimentary. The rebatable tax should promote recycling, if the materials tax on non-recyclables is adjusted so that the consumer makes the ''right'' selection of the recyclable package. And, if the incentive award system to the scrap generated were not instituted, the taxation scheme outlined above would only tend to generate scrap plastic from the consumer sector at the expense of that from industry, because the price of scrap plastic would probably drop as the total supply increased. Therefore, the industrial scrap generator would have less incentive to isolate, store, and bale his scrap as he received less and less money for it.

Special Requirements of This Program. This program can only operate if an effective collection system exists, as emphasized above. Collection centers and systems for separate home collection of selected packaging material are relatively new activities that are currently in the experimental stage. Before the rebatable tax scheme is instituted, however, these systems will have to be improved and their costs analyzed.

The administrative costs of this program are no doubt the highest of any program discussed previously. The need to develop a working arrangement between the Federal and local government groups further complicates the successful operation of the program.

Improvement of Solid Waste Management Practices

The tax revenues that would be realized by some of the tactics outlined above could well be used to contribute to the general improvement of the current systems of disposing of nuisance plastics, including collection and final disposal. Here again, it is obvious that we cannot isolate the cost of disposal of NP from that of other spent materials. Funds could be channeled to the local government, for example, according to the population served. To insure that the funds would be used appropriately to solve local solid waste problems, a preferred approach would be to request the local governments to first develop their own plans of action for improving their disposal and collection processes before they would be offered Federal funds. This would be similiar to the present grant system. Funding, then, would continue on an annual basis to the extent that the local governments operated effective programs; thus, an agency such as EPA would have to review programs at least annually. Again, we believe that local funds should be contributed to this program, and a 90/10 split between local and Federal governments would be appropriate, with the local government contributing the lesser share.

This tactic is not addressed to promoting recycling but to reducing the environmental damage of those spent products that cannot be recycled either for technical or economic reasons.

Incentive Programs for the Reprocessor

To meet the economic impediment head on, the government can reduce the reprocessing costs directly by providing easy financial conditions for operating a reprocessing business. This may be provided in the form of tax credits, special depreciation allowances, low-interest loans, and similar mechanisms. Easy financing could be made available to the reprocessors for the purchase of equipment to improve their general technology, such as better separation equipment, granulators, choppers, balers, etc.

These incentives will reduce the costs for secondary resins and thereby increase demand. Furthermore, this approach should keep recycling technologically advanced and secondary resins more competitive with virgin resins.

Direct Purchase of Scrap by the Government

An alternative mechanism for reducing the cost of secondary resins would be to have the Federal Government itself purchase scrap plastic at a relatively high price and then sell it to a reprocessor at a lower price. Under this arrangement, of course, no separate reimbursement scheme would be required, as outlined in the section dealing with an incentive payment for the use of secondary material. This mechanism has some merit, because initially the markets for secondary plastics will develop slowly. Thus, using this mechanism, the Federal Government could stockpile the secondary materials and perhaps even assist in developing markets by requesting competitive bids for the secondary material. Conceivably, under these circumstances, companies could even bid a negative sum, which would provide an incentive to the bidding company to develop appropriate applications for the secondary material. However, the bidding company would have to clearly demonstrate that they were not merely disposing of the scrap. This program, however, would require careful administration, because the government would be directly involved with the private sector.

STRATEGIES THAT DO NOT REQUIRE LEGISLATION

The Federal Government can institute various programs that will not require Congressional action. These are primarily programs of education, information, and research.

Educational Programs

Most of the economic incentive programs discussed above should be supported by educational programs directed both at the consumer and industry. These programs, for example, could include the training of operators of collection centers and those needed by the rejuvenated reprocessing industry. Through these programs the government should be able to educate the public that products containing secondary material can perform equally as well as those containing solely virgin material.

The Environmental Protection Agency already is involved in an extensive program to educate both industry and the public at large to the problems of solid waste management. The seminar technique, which has been used periodically, is an attrative one, and we recommend that the practices of bringing together representatives of industry, local sanitation officials, researchers, and government officials in regional conferences and seminars should continue. A series of symposia and seminars each year would be very appropriate; these should be very helpful in ‘‘clearing the air.’’ Hopefully, these should lead to voluntary actions by industry. With respect to the plastics industry, these meetings also could be useful as a medium for educating fabricators. For example, in this way they could become familiar with new secondary resins that would be developed and new applications for secondary materials.

If the rebatable tax scheme for the consumer is initiated, this would similarly require educational programs to make them fully aware of the objectives and mechanisms of the taxation schemes. This can be effected by advertising and demonstration programs. However, preliminary to actually setting up a system for recycling plastic containers through a collection center, as mentioned above, we strongly advise that the Federal Government institute a number of demonstration programs in selected metropolitan centers to determine how effective a collection center can be as compared to collection from the home and as compared to no collection. These demonstration programs also will be useful in gaining practical experience and information related to consumer response and actual costs. Ultimately, the question is whether the collection center approach is a viable one.

Information Programs

A major impediment that has blocked extensive recycling is the fabricator's lack of confidence in the quality of secondary resins.

In an effort to improve and assure the quality of secondary resins, we recommend that the Federal Government together with the plastics industry develop a certification program, so that standard grades of secondary resins will become available similar to those for the virgin products; the secondary resins, in effect, would have to meet certain ASTM or other new inudstrial standards.

Still another action that the government in cooperation with the plastics industry can take to assist in promoting recycling would be to set up an inventory of all sources of scrap plastic. This inventory would describe the availability, location, physical, and chemical forms, etc., of the scrap, and it would be a resource for fabricators interested in purchasing secondary material.

Because off-grade virgin resins, especially surplus, compete with secondary resins, an effective tactic would be to reduce the available volume of this surplus resin. If government and industry and cooperate to develop a program for monitoring and reporting virgin-resin inventory levels, this will go a long way towards stabilizing resin prices and, therefore, prevent the production of large volumes of surplus off-grade resin.

Research Programs

A very worthwhile use of some of the tax revenues would be to further research and development specifically directed at making reprocessing technically and economically more attractive. For example, research programs directed at developing new applications for scrap materials obviously will be very helpful to the reprocessor and should promote recycling. Further, research to develop new technology for collecting and disposing of scrap plastic is still another positive approach that can be taken.

With regard to those products that are essentially not recyclable, the government could initiate a research study directed at developing a realistic disposability index. This would be rewarding, because alone (i.e., without the use of a taxation scheme) it might provide an excellent incentive for the packager to make the ''right'' selection of the package least damaging to the environment, as Freimen[52] has recommended. In this way, a packager could select a package that would have minimal environmental damage during disposal. Even without the threat of taxation, the packager today has become more aware of the environmental problems and he would, no doubt, use this concept to demonstrate his social responsibility. Furthermore, the easily disposed package is good advertisement, as some packagers are now beginning to realize.

Government Purchasing Policy

As noted in Part IV, the government itself often impedes recycling because it uses purchase specifications that disallow the use of secondary resins, in spite of their limited effect on performance in certain applications. Therefore, the Federal Government is in an excellent position to take the lead by relaxing these restrictions wherever possible, and thus open up additional markets. The Federal Government spends approximately $50 billion per year for a large array of products and, therefore, by modifying its procurement policy the government can increase the recycling of secondary materials. By specifying the use of secondary materials in their purchases, the Federal Government would not only open up a new market by its own purchases but, more significantly, their actions would have an important positive effect on state and local governments, public agencies in general, and many segments of industry. Many would tend to follow the Federal Government's lead.

RECOMMENDATIONS

Although the tactics and strategies described above that do not require legislative action will be easier to institute, they are really only auxiliary programs to meet the objective of this study, namely to promote the recycling of plastics. Alone, the programs concerned with research information and government purchasing will make recycling of plastics easier to occur. For example, changing government specifications, developing an inventory of scrap plastic sources and off-grade resins, and a certification system for secondary resins would tend to increase the demand for secondary materials. But these are not key programs that will reverse the trend toward the use of a decreasing concentration of recycled plastics in plastic products. These programs will have only a small effect on the economic impediment that is preventing recycling.

On the other hand, the programs that will require legislation are directed at widening the gap between the prices of secondary and virgin resins. We believe that an incentive payment to promote recycling, as discussed above, can go a long way toward increasing the recycling of plastics at a minimal cost. This program can be initiated for plastics alone, if that is desirable, but most importantly this program does not require auxiliary legislative programs to operate effectively.

Providing easy financing for the reprocessor is similarly a program that does not require other legislative programs, but this tactic will not be as effective as the incentive payment to promote recycling. However, it has the advantage, in comparison to the latter, that the administrative costs would be low.

The tax on virgin materials should only be used as an auxiliary tactic, because it requires an additional tactic to increase the availability of scrap plastic. Furthermore, this tax must apply to all materials; therefore, a careful analysis of the impact of this tax on our economy will be required, before the tax is levied.

The rebatable and materials tax schemes similarly cannot be used alone, and they must apply to all materials. These two taxes must be levied together to achieve the desired effect of minimizing environmental damage by promoting the ‘‘right’’ decision throughout the plastics cycle. Alone, neither the materials tax nor the rebatable tax will promote recycling. These two tax schemes have the further disadvantage that they will require extensive preliminary analysis, and once instituted they will probably be the most expensive programs to administer, as compared to the others cited above.

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APPENDIX A

We have developed a system of classifying nuisance plastic (NP) and have adopted code numbers for each category. Basically there are two types of NP--one is generated in a non-distinctive form as strands, lumps, powder, etc., and the other in the actual or damaged form of the intended product. The first type is classified as process NP and the latter product NP. In the plastics cycle, process NP is generated by all segments except the manufacturer/packager, wholesaler/retailer, and consumer segments. These latter segments generate product NP.

Process NP is catalogued using a five digit coding structure with three digits on the left side of the decimal point and two digits on the right side. Product NP can have as many as an eight-digit coding structure with five digits on the right side of the decimal point.

Process NP

Code No. 000.000. Proceeding right from the decimal point, the first digit identifies the segment producing the NP, and these code numbers are listed in Table 53; and, the second digit identifies the resin categories which are listed in Table 54.

Proceeding left from the decimal point, the first digit identifies the operation (polymerization, etc) producing the NP, and these code numbers are listed in Table 55, and the second and third digits identify the fabrication or converting process producing the NP. These code numbers are listed in Tables 56 and 57.

Product NP

Code No. 000.000. Proceeding right from the decimal point, the first two digits are the same as described above, but the third digit identifies the physical form of the product only as it is related to packaging. These code numbers are listed in Table 58. Whether this digit is applicable or not, it is carried along using a mill to identify the NP as product rather than process NP. The fourth and fifth digits identify the service life of the product. These digits are only used to identify products disposed of by the consumer. A spent product disposed of within one year is identified

TABLE 53

SEGMENT CATEGORIES

Sector	Code no.
Resin producer	1
Compounder	2
Fabricator	3
Convertor	4
Manufacturer/packager	5
Wholesaler/retailer	6
Reprocessor/compounder	7
Consumer	8

TABLE 54

RESIN CATEGORY

Resin type	Code no.
HDPE	1
LDPE	2
Polypropylene	3
Styrene polymers	4
PVC	5
Polyolefins	6
All categories	7

TABLE 55

OPERATION PRODUCING

Operation	Code no.
Polymerization	1
Addition of additive	2
Addition of colorant	3
Prepare for shipment	4
Storage	5
Fabrication	6
Off grade/reject production	7
Converting	8
Assembling/packaging	9
Reprocessing	0

TABLE 56

FABRICATION CATEGORIES

Fabrication process	Code no.
Blow molding	10
Injection molding	11
Extrusion, film and sheet	12
Extrusion coating	13
Extrusion on wire and cable	14
Profiles	15
Coextrusion	16
Calendering	17
Calender coating	18
Coating	19
Compression molding	20
Slush molding	21
Rotomolding	22
Foam processing	23

TABLE 57

CONVERTING CATEGORIES

Converting process	Code no.
Decorating - 3 dimensional	50
Decorating - film	51
Bag making (exclusive of printing)	52
Bag making (unprinted)	53
Cutting	54
Thermoforming	55

TABLE 58

PHYSICAL FORM

Form	Code no.
Rigid-monoplastic	1
Rigid-composite	2
Rigid-multiplastic	3
Flexible-monoplastic	4
Flexible-composite	5
Flexible-multiplastic	6
Not pertinent	0

by these two digits as ‘‘01’’ and another disposed of after 10 years is identified by the two digits as ‘‘10’’.

Proceeding left from the decimal point, the first digit is the same as described above, but the second and third digits identify the product category. These code numbers are listed in Table 59.

TABLE 59

PRODUCT CATEGORIES

Product	Code no.
Packaging	1
Housewares	2
Toys	3
Automotive and transportation	4
Appliances	5
Furniture	6
Footwear	7
Construction and agricultural film	8
Construction	9
Wire and cable	10
Novelties, disposable dinnerware, hospital goods, etc.	11
Sporting goods	12
Luggage	13
Records	14
Apparel	15
Business machines, including phones	16

APPENDIX B

Measurement Problems

Scales. The most basic way of comparing an attribute of two different objects A and B is to say that A is heavier than B, A is greater than B, A is darker than B, etc. Such observations are qualitative statements and constitute the most elementary of all measurements. Simple ranking of objects either in increasing order or decreasing order of attributes sufficiently expresses such measurements. Simple ranking does not contain any information of the magnitude of the difference between the attributes of individual objects. For example, if we know that objects A, B, and C have been ranked with respect to their weight, then we do not know whether B and C together are heavier than A. A may be 1,000 times heavier than B, or it may be just slightly heavier than B. Thus, an ordinal scale contains only very limited information.

In a second-order ranking, certain additional information can be provided. This second-order ranking indicates the ordering of differences between the attributes of objects in either increasing or decreasing order. An example would be that the difference in weight between objects B and C is larger than the difference in weight for objects A and B. From this information we still cannot deduce whether A is heavier than B and C together, for more information still has to be collected until eventually the measurements can be represented by a numerical scale such as a ratio scale or an interval scale.

In this study, it was not possible to devise an actual measure of the overall effectiveness of an alternative strategy such that a unique correspondence existed between a measure and a real number. However, we did essentially rank strategies using an ordinal scale.

Trade-Offs. The term ''trade-off'' used or inferred in this report describes the relative contribution of a particular objective to some overall criteria of preference or effectiveness. Consider the evaluation of an automobile. Two of the many objectives to be considered are: (1) to maximize maneuverability; (2) to maximize comfort. Suppose that each of these objectives is measured on a scale of from 0 to 100. Usually a larger car offers more comfort but is less maneuverable. Thus, comfort must be traded off against maneuverability. Consider a particular car with a maneuverability rating of 75 and a comfort rating of 50. If another car with a maneuverability rating of 70 and a comfort rating of 60 is just as desirable, then 5 points of maneuverability can be traded off against 10 points of comfort. Thus, the trade-off of comfort vs. maneuverability is 2 whereas the trade-off of maneuverability is 0.5.

These trade-offs are generally functions of scale values. It means, for example, that a different trade-off may apply for a car with a maneuverability rating of 45 and a comfort of 60. Any method of collapsing a multi-objective description such as this one into a scale index of preference or effectiveness must employ trade-offs. This concept of trade-offs was used implicitly in this study; however, we were not able to put it on a quantitative basis.

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